Modeling of Supply Chain Risks in the Leather Industry

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Abstract

The leather industry is one of the key contributors to the economy of Bangladesh. This industry is flourishing rapidly, but at the same time giving birth to complicated and severe risks in its supply chain. The purpose of this study is to identify, categorize and analyze these risks, which are creating vulnerabilities in the supply chain of the leather processing industry of Bangladesh. To assess these risks, the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation technique are applied. Firstly, through a thorough review of literature which is afterwards enhanced by an elaborate discussion with specialists in the field of leather industry, four main risk factors (external, demand, supply, and operational) and 16 sub-risks are selected. Later, the relative weights of the main and sub-risks are determined using the AHP. Finally, the level of risk of the whole industry is quantified applying the fuzzy comprehensive evaluation technique. The outcomes of this work point out that the current risk index of the supply chain of the leather industry resides between low and moderate risk level. The results also indicate that supply and external risks are more threatening to the supply chain of this industry than demand and operational risks. This analysis is expected to aid industrial managers in tackling supply chain risks in the leather industry more conveniently.

Keywords:

Supply Chain Risk, Leather Industry, AHP, Fuzzy Comprehensive Evaluation

1. Introduction

Previously, supply chains of enterprises mainly focused on accelerating profit. However, in recent days compliance and quality are considered as cardinal factors especially in export business (Paksoy et al., 2019). To support this idea, Zsidisin et al. (2004) conceptualized supply risk as reduced quality of products and services caused by delayed supply. Also, supply chain risk assessment is crucial to agribusiness than manufacturing supply chain for its seasonality, long supply lead time and supply spikes (Behzadi et al., 2017). Since supply chain across industries are extremely stretched, many factors are posing potential threats to make the supply chain vulnerable. Moreover, globalization impel industries to adopt new business practices which include considerable amount of risks (Vishnu et al., 2019) Any potential for unwanted negative consequences towards the supply chain has been considered as a risk factor in this framework. In another work, risk has been defined as the expectation of loss where the probability of loss is proportionate with the risk (Mitchell, 1999). Now business environment has become uncertain and prone to vulnerability more than ever due to complex relationship among the supply chain stages (Prakash et al., 2017).

The leather industry soared up in an enormous scale in Bangladesh in the 1970s as one of the largest businesses in the country and the government welcomed it as a significant growth generator of the country. Bangladesh has got the competitive advantage over other competitors because of availability of hides and skins, their fine grain pattern, uniform fibre structure and competitive labor cost. Moreover, the agro based economy has helped to proliferate this by-product industry with available indigenous raw materials with prospective for sustainable export growth over the coming years through attracting both foreign and local investments by assuring business friendly environment (Khan, 2019; Paul et al., 2013). At present, Bangladesh fulfills the need for about 10% of the world's total leather market and the main export markets are: UK, USA, Australia, Singapore, South Korea, Germany, China, Japan, Spain, Italy, France, and UAE (Hoque & Clarke, 2013; Khan, 2019). However, this second largest export-earning industry is facing a continuous dwindling in export-earning. As per the data of Export Promotion Bureau (EPB), export earnings from the leather and leather products dropped by 16.11% to US$434 million in the five months of the fiscal year 2018-19, which was US$518 million in a similar period a year ago (Akhtar & Al Mahfuz, 2018).

Even though a wide range of studies can be found on assessing the supply chain risk of some specific industries (e.g., the chemical industry (Lu, 2015), the pharmaceutical industry (Li et al., 2016; Moktadir et al., 2018), assessment of supply chain risk factors of leather industry is nonexistent. The International Finance Corporation (IFC) has arranged a roadmap delineating a strategy for improving the nation's leather industry exports. The roadmap sets a dream of positioning Bangladesh among the best 10 leather export nations on the planet by 2025 from the present diminutive scale (Khan, 2019). From the perspective of effective supply chain structure, any measure taken for managing the supply chain risk factor may have great impact in this rapidly evolving period. This paper presents supply chain risks evaluation in the leather sector of Bangladesh using a unified method consisting of AHP and fuzzy comprehensive evaluation.

The rest of the paper is organized as follows. Section 2 presents the literature review. The solution methodology has been depicted in Section 3. Section 4 includes the application of AHP and fuzzy comprehensive evaluation to assess the risks in the leather industry's supply network. An analysis of the results has been mentioned in Section 5. Lastly, the research is concluded in Section 6.

2. Literature Review

The extensive research of supply chain risk and their management has widely canvassed the literature over the past years (Hallikas et al., 2002; Lockamy, 2011; Tang, 2006; Zsidisin et al., 2004). Even though a diverse amount of definitions can be found on both supply risk and supply chain risk, researchers and practitioners have inferred them to apply in specific domain (Ellis et al., 2010; Jüttner et al., 2010; Zsidisin, 2003). In the definition of supply chain risk, Zsidisin (2003) discussed the probability of failing the customer demand and in another definition Jüttner et al. (2003) mentioned the risk associated with information, material and product flows only. Based on 827 disruption announcement, supply chain risk prevention is considered as a salient function as firms are not capable of recovering quickly from the negative effects of disruption (Hendricks & Singhal, 2005). However, the risk mitigation and prevention procedures are pivoted on risk assessment which is the fundamental step of this whole process (Prakash et al., 2017). Risk assessment is basically the identification, analysis and further evaluation of the risk associated with exposure which also includes identification of underlying risk and scope of the influence, estimation and understanding of the associated risk (Li et al., 2016).

Typically, the supply chain risk is associated with disruption and delay caused by supply risk but has multiplex factors affecting this (Chopra & Sodhi, 2004a; Giannakis & Papadopoulos, 2016a). Again, a specific risk type can be driven by multiple events or situations (Ho et al., 2015). This risk assessment is quite challenging in terms of its cross company assessment as it focuses on the whole supply chain (Thun & Hoenig, 2011). Moreover, 44% of the responding companies are expecting an inflation in supply chain vulnerability during the next five years (Juttner, 2005).. Even though a few research emphasized on some specific industries e.g., chemical industry (Lu, 2015), pharmaceutical industry (Li et al., 2016), automotive industry (Thun & Hoenig, 2011) and toy industry (Johnson, 2001), none of them has either identified or evaluated the concomitant supply chain risk of the leather industry yet. Moreover, 90% of the leather market which is considered as the second largest export earner in Bangladesh is controlled by 220 tanneries, 3,500 Small and Medium Enterprises (SME) and 110 large firms (Moktadir et al., 2018). Therefore, assessing the supply chain risk of the leather industry can be proved beneficial to the nation's economic growth.

Through a comprehensive literature review along with expert opinion, the most relevant risk factors for the leather industry have been finalized (Table 1).

3. Solution Methodology

In this study, AHP is used to calculate the weights after creating the comparison matrices whereas fuzzy comprehensive evaluation technique is utilized to assess the risk level and evaluation of the secondary risk factors. Views of 5 experts have been incorporated during calculation of the weights of primary and secondary risk factors.

Likewise, 20 experts were assigned the task of providing their views on the probability and severity of the 16 secondary risks which were used afterwards in the risk evaluation process.

Table 1: Supply chain risk factors with supporting literature

Primary Risk Classification	Secondary Risk Factors	References
External Risks (R1)	Political Instability (R11)	(Cucchiella & Gastaldi, 2006; Samvedi, Jain, & Chan, 2013)
	Government Restrictions (R12)	(Rao & Goldsby, 2009; Tummala & Schoenherr, 2011)
	Labor Unrest (R13)	(Blackhurst, Scheibe, & Johnson, 2008; Wu, Blackhurst, & Chidambaram, 2006)
	Economic Recession (R14)	(Chopra & Sodhi, 2004b; Prakash et al., 2017)
Demand Risks (R2)	Inaccurate Forecasts (R21)	(Chopra & Sodhi, 2004b; Manuj & Mentzer, 2008)
	Competitive Market (R22)	(Blos, Quaddus, Wee, & Watanabe, 2009; Tuncel & Alpan, 2010)
	Bullwhip Effect (R23)	(Chopra & Sodhi, 2004b; Craighead, Blackhurst, Rungtusanatham, & Handfiel, 2007)
	Demand Uncertainty (R24)	(Hahn & Kuhn, 2012; Manuj & Mentzer, 2008)
Supply Risks (R3)	Delay in Supplies (R31)	(Blackhurst et al., 2008)
	Single Supply Source (R32)	(Tummala & Schoenherr, 2011; Wagner & Neshat, 2010)
	Supply Quality Issues (R33)	(Kull & Talluri, 2008; Manuj & Mentzer, 2008)
	Increased Price of Supplies (R34)	(Blos et al., 2009)
Operational Risks (R4)	Poor Product Quality (R41)	(Hahn & Kuhn, 2012; Schoenherr, Tummala, & Harrison, 2008)
	Machine Breakdown (R42)	(Z. Yang & Li, 2010)
	Inflexible Production System (R43)	(Chopra & Sodhi, 2004b; Wu et al., 2006)
	Unskilled Labor and Labor Absenteeism (R44)	(Chowdhury, Dewan, & Quaddus, 2012; Tuncel & Alpan, 2010)

3.1 Analytic Hierarchy Process (AHP)

Introduced by T.L. Saaty (1980), AHP is a widely known and applied multiple criteria decision making (MCDM) tool because of its suitability to deal with complexities in decision making that arise while comparing some elements which are not easy to quantify (Kabir & Hasin, 2011). The purpose of AHP is to divide the complex problem into some ordered levels and then a fuzzy judgement is utilized to quantify the relative importance of one level over another. Finally, through mathematical operations, this relative importance of the different elements in different levels is converted into weights (Lu, 2015; F. Yang et al., 2009). AHP is much simpler to apply, often requiring less pair-wise comparisons and therefore preferred to other MCDM tools such as analytic network prcess (ANP) and technique for order of preference by similarity to ideal solution (TOPSIS) (Luthra, Govindan, Kannan, Mangla, & Garg, 2017). The principle steps while applying AHP are presented in the following.

Step 1: The single large problem is divided into different levels and a hierarchical structure is obtained.

Step 2: Based on the relative importance, elements located under the same level are compared and then quantified in an *n x n* comparison matrix using the values given in Table 2.

Table 2: The values for comparing one criterion with other

Numerical Rating	**Explanation**
1	Factor *i* is equally important to factor *j*
3	Factor *i* is slightly more important than factor *j*
5	Factor *i* is obviously more important than factor *j*
7	Factor *i* is strongly more important than factor *j*
9	Factor *i* is extremely more important than factor *j*
2, 4, 6, 8	Intermediate values

A judgment matrix is constructed following this procedure which is illustrated in Figure 1. From Table 2, $a_{ij} = 7$ states that factor i is strongly more important than factor j. If , $a_{ij} = X$, then for consistency, $a_{ji} = 1/X$. Moreover, as seen from Figure 1, the factors along the diagonal (a_{ii}) are all equal to 1 since these factors are compared to themselves.

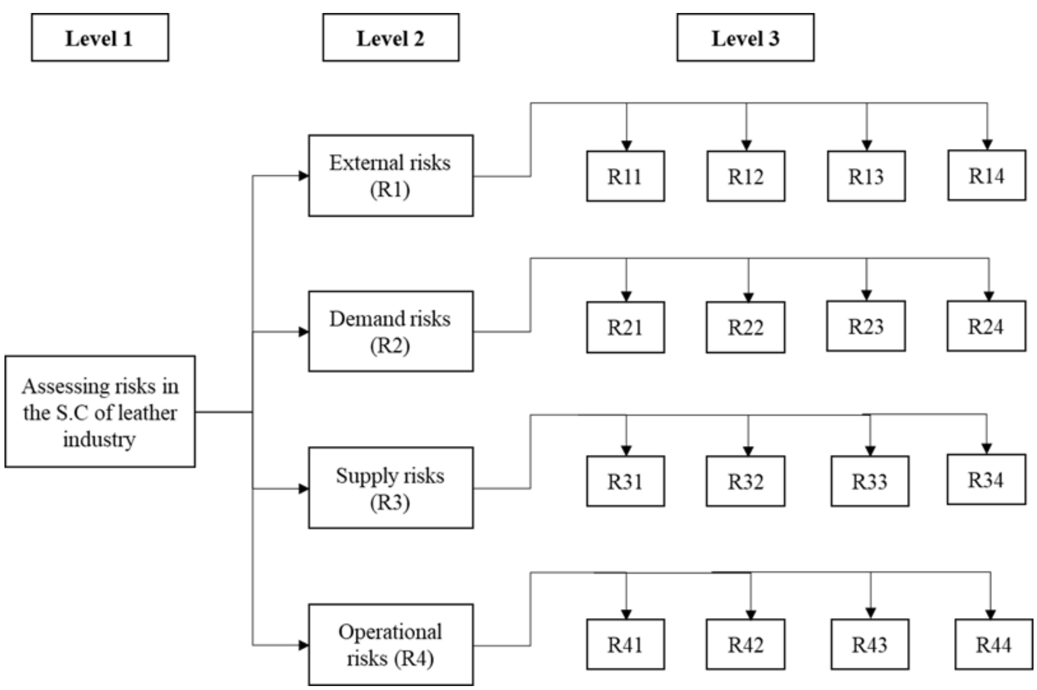

Figure 1: Three level hierarchical model of risk assessment

Step 3: The geometric mean of factors in each row calculated utilizing the following equation:

$$b_x = [a_{x1} \times a_{x2} \ldots a_{xn}]^{1/n} \quad (1)$$

Here, $x = 1, 2, 3 \ldots n$

Step 4: In this step, the normalized weight for each factor is determined applying the following equation:

$$W_x = \frac{b_x}{\sum b_x} \quad (2)$$

Here, $x = 1, 2, 3 \ldots n$

Step 5: This step deals with the verification of the consistency ratio which is presented in the equation below:
Consistency Ratio, CR = CI / RI (3)
Here, CI = Consistency Index and RI = Randomly Generated Consistency Index
Table 3 shows some RI values for different sizes of comparison matrices. To calculate CI, the following sub steps are performed:
(1) Summing the factors in each column of the judgement matrix which gives the values $c_1, c_2, \ldots c_n$
Here, c_1 represents the summed values of column 1, c_2 represents column 2 and so on.
(2) Largest eigen value is computed from the following equation:

$$\lambda_{max} = c_1.W_1 + c_2.W_2 + \ldots + c_n.W_n = \sum c_n \,.\, W_n \quad (4)$$

(3) Finally, CI is calculated with the help of the following equation:

$$\text{CI} = (\lambda_{max} - n) / (n - 1) \quad (5)$$

CR is usually acceptable if it is less than 0.1 for matrix of order 4 and higher.

Table 3: Randomly Generated Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.2 Fuzzy Comprehensive Evaluation

Based on fuzzy mathematics, fuzzy comprehensive evaluation is quite handy during the quantification of multivariable decision making complex problems (Li et al., 2016). The steps involved in fuzzy comprehensive evaluation are mentioned in Table 4.

Table 4: Steps in fuzzy comprehensive evaluation

Step	Performed Activity	Equation/Source
1	Defining the index set	R = {R1, R2, R3, R4} R1 = {R11, R12, R13, R14} R2 = {R21, R22, R23, R24} R3 = {R31, R32, R33, R34} R4 = {R41, R42, R43, R44}
2	Setting the appraisal set	U = {1, 2, 3, 4, 5} = {Lower Risk, Low Risk, Moderate Risk, High Risk, Higher Risk}
3	Determining the weights which has been already determined using AHP	Described through the equations mentioned in section 3.1
4	Establishing the single factor evaluation matrices or assessment matrices	Obtained from the opinions of 20 experts on the probability and severity of each secondary risk factor
5	First level comprehensive evaluation to determine ultimate assessment vectors	$F_i = W_i.A_i$ for $i = 1, 2, \ldots n$
6	Second level comprehensive evaluation	$F = W.A$
7	Determining the general risk level of the industry	$Level\ of\ Risk = F.U^T$
8	Calculating the risk levels of the primary and secondary risk factors	Relative Risk Level of Primary Risks, $RL_i = F_i.U^T$ Relative RL of Secondary Risks, $E = P.U^T$

4. Assessing the Risks in the Supply Chain of Leather Industry

The calculations performed to get the desired results can be divided into two phases, the first phase uses AHP to calculate the weights and the second phase uses these weights alongside data from 20 experts to evaluate the risks.

4.1 Applying AHP to Calculate the Weights

In this section, pair-wise comparisons have been conducted among the primary risk classification which contains 4 risks as well as the secondary risks under them. AHP has been utilized in this purpose to calculate the weights of these risks from the pair-wise comparison matrices constructed from the judgement of five experts. The necessary steps are discussed below:

Step 1: The three level hierarchical model is shown in Figure 1.

Step 2: With the help of Table 2, the input from the first expert is used in constructing the judgement matrix for the primary risk classification. This is presented in Table 5.

Table 5: Initial judgement matrix for primary risk classification from opinion of first expert

Primary Risk Classification	**R1**	**R2**	**R3**	**R4**
R1	1	3	3	3
R2	1/3	1	1/5	1/3
R3	1/3	5	1	3
R4	1/3	3	1/3	1

Five experts responded in the construction of the judgement matrices. Taking the average from their responses, the final judgement matrix for the primary risk classification is shown in Table 6 which also contains the geometric mean, weights and column sums of the risk factors.

Table 6: Final judgement matrix for the risks in the primary classification

Primary Risk Classification	**R1**	**R2**	**R3**	**R4**	**b_x**	**W**
R1	1.00	2.40	1.53	1.67	1.57	0.37
R2	0.42	1.00	0.45	0.56	0.57	0.13
R3	0.65	2.20	1.00	2.20	1.33	0.31
R4	0.60	1.80	0.45	1.00	0.84	0.19
Summation	2.67	7.40	3.44	5.43	4.31	1.00

Step 3: From Table 6, using equation (1), geometric mean of the first row is obtained as follows:
$b_1 = (1 \times 2.40 \times 1.53 \times 1.67)^{1/4} = 1.57$
In the same fashion, the other geometric means are determined and shown in Table 6.

Step 4: With the help of equation (2), the weight of first factor (R1) is calculated as follows:
$W_1 = \frac{1.57}{4.31} = 0.37$
Similarly, the weights for the remaining factors are calculated and the weight matrix is presented in Table 6.

Step 5: To test the consistency, firstly, using equation (4), the eigen vector is determined as follows:
$\lambda_{max} = 2.67 \times 0.37 + 7.40 \times 0.13 + 3.44 \times 0.31 + 5.43 \times 0.19 = 4.07$
Equation (5) is applied afterwards to obtain CI and finally using equation (3) and Table 3, CR is calculated.
$CI = \frac{4.07-4}{4-3} = 0.023$ here, $n = 4$
$CR = \frac{0.023}{0.90} = 0.026$ which is less than 0.1. Therefore, the consistency is satisfactory.
In the same manner, using the steps above, the judgment matrices for each primary risk are created from the average of the opinion of the five experts and consequently, the weights are also determined. This is summarized in Table 7.

Table 7: Weights of the primary and secondary risk factors

W	0.37	0.13	0.31	0.19
W_1	0.09	0.59	0.22	0.09
W_2	0.16	0.45	0.30	0.09
W_3	0.34	0.12	0.31	0.23
W_4	0.33	0.14	0.29	0.24

4.2 Evaluating the Risks with Fuzzy Comprehensive Evaluation

Data for the single factor evaluation matrices was collected from 20 experts with various level of experiences working in the supply chain of five different leather processing companies. The experts helped to rate the current magnitude of the secondary risk factors depending on their probability to occur and severity. A scale of 5 was chosen for this purpose. With the data obtained from these experts, after comprehensive calculations, the assessment matrices, as mentioned in step 4 of Table 4, are determined and presented in Table 8.

Table 8: Assessment matrices of the four primary risks

Primary Risk Classification		**U1**	**U2**	**U3**	**U4**	**U5**
P	**A1**	0.10	0.75	0.10	0.05	0.00
		0.00	0.35	0.45	0.20	0.00
		0.10	0.55	0.20	0.15	0.00
		0.35	0.45	0.20	0.00	0.00
	A2	0.30	0.55	0.15	0.00	0.00
		0.05	0.55	0.30	0.10	0.00
		0.05	0.70	0.25	0.00	0.00
		0.25	0.75	0.00	0.00	0.00
	A3	0.00	0.40	0.30	0.25	0.05
		0.20	0.70	0.10	0.00	0.00
		0.00	0.40	0.55	0.05	0.00
		0.10	0.60	0.20	0.10	0.00
	A4	0.00	0.55	0.45	0.00	0.00
		0.25	0.60	0.15	0.00	0.00
		0.10	0.75	0.15	0.00	0.00
		0.00	0.65	0.30	0.05	0.00

Afterwards, from step 5 of Table 4, the ultimate assessment vectors are determined and shown in Table 9.

Table 9: Table of ultimate assessment vectors

A	**F1**	0.0625	0.4355	0.3365	0.1555	0
	F2	0.108	0.613	0.234	0.045	0
	F3	0.047	0.482	0.3305	0.1235	0.017
	F4	0.064	0.639	0.285	0.012	0

Subsequently, from the equation in step 6 of Table 4, second level comprehensive evaluation is performed which gives the membership vector, F shown in the following:

F	0.0639	0.51166	0.31153	0.10395	0.00527

The overall risk level is found from step 7 of the same Table 4 which is equal to 2.46. Finally, using the equations depicted in step 8, the relative risk levels of the primary and secondary risks are calculated. These are presented in Table 10.

Table 10: Ranking of the primary risks and secondary risk factors according to risk level

Primary Risk Classification	**Risk Level**	**Ranking**	**Secondary Risk Factors**	**Relative Risk Level**	**Ranking**
External Risks (R1)	2.565	2	Political Instability (R11)	2.100	10
			Government Restrictions (R12)	2.850	2
			Labor Unrest (R13)	2.400	6
			Economic Recession (R14)	1.850	14
Demand Risks (R2)	2.216	4	Inaccurate Forecasts (R21)	1.850	15
			Competitive Market (R22)	2.450	4
			Bullwhip Effect (R23)	2.200	9
			Demand Uncertainty (R24)	1.750	16
Supply Risks (R3)	2.581	1	Delay in Supplies (R31)	2.950	1
			Single Supply Source (R32)	1.900	12
			Supply Quality Issues (R33)	2.650	3
			Increased Price of Supplies (R34)	2.300	8
Operational Risks (R4)	2.245	3	Poor Product Quality (R41)	2.450	5
			Machine Breakdown (R42)	1.900	13
			Inflexible Production System (R43)	2.050	11
			Unskilled Labor and Labor Absenteeism (R44)	2.400	7

5. Discussion of Results

In this research, the current level of risk of the supply chain of the leather industry of Bangladesh has been quantified which turns out to be 2.46. Comparing with the five-level appraisal set mentioned in step 2 of Table 4, the present risk scenario is in between low and moderate risk level. The situation may seem under control for the moment, however, as complexities in the supply network continue to magnify in this industry, conditions can deteriorate rapidly and this risk level may aggravate within a very short time. There are 4 primary risk categories, and according to Table 10 these are positioned as: Supply Factors > External Factors > Operational Factors > Demand Factors. The risk levels of the supply factors and external factors are very close to each other and comparatively higher than operational and demand factors. Concerned personnel can thus exert more effort in minimizing the supply and external risk factors which will aid in dwindling the overall risk level. By contrasting among the 16 secondary risk factors, it is clear from Table 10 that "Delay in Supplies" has the largest impact on this industry whereas "Demand Uncertainty" bears the least damage. The vulnerable infrastructure and improperly maintained transportation system of this country could be behind the frequent delays in supplying the raw material. Moreover, factors such as "Government Restrictions" and "Supply Quality Issues" occupy the second and third position respectively that indicate an immediate focus on these. The leather industry is an industry of red category which is notorious for its capability in polluting the environment like no other industry. As a result, businesses in this industry are frequently hindered by government regulations and policies. The buyers of leather products are mainly the shoe manufacturing companies having a stable demand which does not fluctuate much with time. This reinforces the reason behind the location of two demand factors, "Inaccurate Forecasts" and "Demand Uncertainty" at the bottom of the ranking.

6. Conclusion

The leather industry is one of the prominent industries in Bangladesh with a prolific growth rate and crucial contribution to the country's economy. However, like all other industries, this industry is not an exemption when it comes to control the risks in its supply chain network. This research initially attempts to identify the most plausible risks that have the greatest possibility to impair the entire leather industry's supply chain. Afterwards, through a unified approach of AHP-fuzzy comprehensive evaluation technique, these vulnerabilities have been successfully quantified and ranked. Moreover, the present risk scenario of the entire industry has also been evaluated, which states neither a low risk level nor a high risk level. The contribution of this research is the determination and evaluation of the risks inherent in the supply chain of the leather industry in Bangladesh, which have significant practical applications and managerial implications.

The outcomes of this study are predominantly dependent on expert opinions. In the future, empirical studies can be conducted on a similar research in the leather industry. Additionally, this work can be extended by providing a list of mitigating strategies, which could be further evaluated by using the AHP or other MCDM tools.

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