A Multi-Criteria Approach to Sustainable Risk Management of Supplier Portfolio: A Case Study at Defense Industry

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Highlights

• This paper focuses on the development of suppliers by focusing on the assessment of risk monitoring.
• This paper focuses on the defense industry and its requirements in forming supplier portfolio.
• An approach is proposed to address different strategies and risk management practices.

Abstract

Supply Chain Management plays an important role in the success and performance of businesses. Supply chains have to adapt to changes in technological advancements and customer expectations to maintain competitive advantage. On the other hand, driving factors such as risk reduction, increasing the financial performance of the supply chain, societal influence, governmental requirements and attracting customers who give importance to sustainability have been influential in the increasing interest in the concept of Sustainable Supply Chain. Therefore, businesses maintain their supply chain operations while focusing on economic, environmental and social dimensions. Additionally, the risk evaluation methods employed in supply chain management are considered to be more qualitative rather than quantitative. This study conducted in a Turkish defense industry company introduces a quantitative framework that allows the evaluation of risks and risk management practices required for sustainable supplier performance with the help of a Multi Criteria Decision Making (MCDM) approach. In this study, Analytical Hierarchy Process (AHP) and Rating Methods are applied together in order to evaluate risks through classification of critical suppliers with respect to business volume, capabilities and schedule certainty. Using this framework, Sustainable Supplier Risk Scores (SSRS) of each class of suppliers have been calculated and specific risk management practices have been determined for each class. The objective is to establish effective supply chain risk management practices, which provide long term partnership with suppliers in a business with strategic customers, high cost of production, high expectations in terms of quality and high level of supply chain risks.

1. INTRODUCTION

Supply Chain and Supply Chain Management is a globally important issue. In competitive business environments, companies aim to create a competitive advantage by benefiting from information and data management. Many international companies have increased the level of outsourcing and are more reliant on the supply chain network as the basis of their competitive advantage. Thus, companies use the capabilities and technologies of suppliers while they focus more on their core competencies. Therefore, choosing unsuitable suppliers will negatively affect the financial and operational stability of a company. The first step in production is to obtain raw materials from suppliers; the ranking and selection of suppliers based on sustainability index are one of the most important and strategic decisions towards establishing a sustainable supply chain. However, in the selection of sustainable suppliers, the issue of risk management is often ignored. Uncertainties and risks encountered in Supply Chain Management adversely affect the productivity of businesses. In this context, businesses have begun to increase focus on the sustainability phenomenon in supply chain risk management by taking into consideration the economic, environmental and social dimensions in the evaluation and management of these risks. The effects and consequences of potential supply chain risks may vary according to the structure of the affected business. At this point, the concept of supplier portfolio management comes up [1-4].

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With the development of globalization and technology, the competitive environment in the business world has become increasingly difficult. Under these challenging conditions, businesses have to reduce their costs, increase their profitability and adapt to changing conditions in order to achieve superiority over their competitors. Businesses that can keep up with developments and changes can stand out in big markets and make a name for themselves. In this context, businesses have turned to the supply chain in order to achieve their desired objectives in the market and to maintain competitive power [5]. Procurement Management, is the "process of identifying, evaluating, selecting, managing and developing suppliers that will realize supply chain performance better than competitors" [6]. "Supply Chain Management is the integrated management of material, information and money flow that enables to reach the right product at the right time, at the right place, at the right price and at the lowest possible cost to the customer" [7].

Facing all these challenges, managers need to respond with realistic models and approaches to the decision-making process, which supports a broader view towards costs and the implementation of sustainability. The ability to determine the benefits of sustainability in a quantitative way is a necessary feature to instill sustainability in supply business models.

This study presents a quantitative framework that enables supply managers to balance the views of a large number of stakeholders and to evaluate the risk and risk management practices required for sustainable supplier performance. Experienced experts and executive persons from the Corporate Risk Management and Supply and Material Management departments of the company where the study is conducted have been contributed to the determination and classification of sustainable risk criteria. Depending on the priorities of the industry, actions proposed for each supplier portfolio will mitigate sustainability risks, thereby reducing costs and minimizing inefficiencies associated with risks, contributing to the development of long-term relations with suppliers. In this context, the aim of the study is to determine the risk monitoring and mitigation methods specific to supplier portfolios by evaluating the risks of supplier classes with a simple decision framework.

In this study, we present a quantitative solution utilizing MCDM by combining the concepts of supply chain management, portfolio management, sustainability and risk management in defense industry. The study also contributes to the development of suppliers by focusing on the assessment of risk monitoring and mitigation practices through qualitative methods, an approach not commonly used in recent works. Finally, the method used in this study differs from other studies in literature in terms of focusing on the defense industry and the requirements of the industry in forming supplier portfolio. The need to address different strategies and risk management practices for the development of the supplier portfolios included in the study are also discussed.

In this framework, the main and sub-risk criteria were determined by considering the studies in the literature and the sector requirements in which the study is conducted. Research has shown that quality, delivery, price and supplier capacity are important criteria in the supplier selection process. According to the results of a study in which 30 criteria have been selected and a survey has been conducted, the most commonly used criteria have been determined as cost, quality, delivery performance, talent and culture. Recent studies indicate that quality is the most important criterion, followed by delivery, cost and capacity [8].

Multi-Criteria Decision-Making methods are widely used to analyze suppliers and select the optimum alternative. Research findings show that Analytic Hierarchy Process (AHP) is the most commonly used technique in supplier selection, followed by linear programming, TOPSIS, ANP, DEA and multi-purpose optimization [8]. Sarkis and Talluri proposed an ANP model to select the best supplier according to the supplier's performance and qualification of pre-evaluation criteria [9]. Gencer and Gürpınar developed an ANP model for an electronics company to evaluate and select the most appropriate supplier according to the main criteria of business structure, production capacity and quality system [10].

AHP method is used to determine the importance degree of main criteria and sub criteria, ranking method is developed to rank the suppliers in terms of risky. The AHP method is based on pairwise comparisons inherent in human beings. In this study, in which the number of criteria, sub-criteria and decision makers

is high, the AHP method was preferred because it takes into account both quantitative and qualitative factors, is easy and simple to use, and allows pairwise comparisons. The Rating method, which is frequently used in the literature for the grading of risks, was preferred in order not to tire the decision maker and to minimize the inconsistency in the sub-criteria.

The remainder of the paper is organized as follows: The literature review is presented in the following section. The methodology used in the study and the evaluation criteria are explained in Chapter 3. The case study in defense industry, involving quantitative assessment of risks for each supplier portfolio through sustainability criteria is given in Section 4. Finally, results and the recommendations for future studies are presented in Chapter 5.

2. LITERATURE REVIEW

Research has shown that quality, delivery, price and supplier capacity are important criteria in the supplier selection process. According to the results of a study in which 30 criteria have been selected and a survey has been conducted, the most commonly used criteria have been determined as cost, quality, delivery performance, talent and culture. Recent studies indicate that quality is the most important criterion, followed by delivery, cost and capacity [8].

The subject of supplier portfolio models has also attracted great interest from researchers. One of the most popular portfolio models, introduced by Kraljic (1983), maintains that the purchasing strategy of a firm depends on two factors: profit impact and supply risks. In the portfolio of Kraljic (1983), purchasing decisions are classified as strategic, bottleneck, leverage and tactical [11]. In another Kraljic study published in 1987, the following steps are proposed to minimize damages that may be encountered during the procurement process and to increase the purchasing power of the business: First of all, purchased materials and parts should be classified according to the effect on profitability and supply risks, then market conditions should be analyzed for these materials and the strategic procurement position should be determined accordingly. Finally, the firm should develop material strategies and action plans [12]. Elliott-Shircore and Steele, 1985; Syson, 1992; Hadeler and Evans, 1994; Scientists such as Olsen and Ellram, 1997 have shown some differences in the original Kraljic matrix [13].

According to the analyses conducted, the use of multi-criteria decision-making techniques in cases where it is difficult to make organizational decisions and where there are multiple criteria / alternatives has been determined to be useful for solving problems within the scope of sustainable supply chain [7]. Multi-criteria decision-making methods can be used to rank alternatives as well as weighting criteria. The literature contains studies that use multi criteria decision-making methods for both purposes. Multi-criteria decision-making methods, which include studies using the aim of weighting the criteria and evaluating alternatives, are shown in Table 1. Table 2 shows articles involving the implementation of sustainable risk assessment and portfolio management in different industries through quantitative methodologies in the last decade.

Table 1. *Multi-criteria decision making methods and their intended use*

MCDM Method	Studies used for weighting criteria	Studies used for evaluating alternatives
AHP	[11, 14-19]	[20-24]
ANP	[25-27]	[21, 27]
BWM	[28, 29]	
DEMATEL	[25, 28]	[26]
MOORA	[30]	
PROMETHEE		[31, 32]
SWARA	[33, 34]	
WASPAS		[34]
TOPSIS	[18, 35]	[29, 31, 36]
WSM		[29]
Entropy	[36, 37]	

Table 2. *Application areas of sustainable risk assessment in different sectors*

Reference	Sector	Year	Supply Chain Management	Supplier Portfolio Management	Selection of Alternative	Risk Evaluation	Sustainability Criteria	Supplier Development
This study	Defense Industry	2020	x	x	x	x	x	x
[11]	Production	2018	x	x	x	x	x	x
[30]	Electronics	2018	x		x	x	x	
[28]	Industrial area	2018					x	
[38]	Logistics	2018	x		x			
[33]	Logistics	2018	x		x	x	x	
[31]	Mining	2018				x	x	
[39]	City planning	2018				x	x	
[40]	Renewable energy	2018			x		x	
[41]	Automotive	2018	x	x	x			
[29]	Purification of wastewater	2017			x		x	
[32]	Food and medicine	2017	x	x				x
[33]	Production	2016	x		x	x		
[21]	Building	2016				x	x	
[25]	Tobacco industry	2015	x			x		
[42]	Transportation	2015				x	x	
[43]	Environment	2015					x	
[17]	Mining	2015				x		
[44]	Health	2013			x	x		
[45]	Energy	2012				x	x	
[15]	Building	2011				x	x	

Selection of the criteria to be used in the MCDM-based sustainable supplier risk assessment problems is as important as the choice of the MCDM method. When selecting criteria, several factors such as the type of industry, number of suppliers, related production projects, business size and public exposure should be considered [46]. The criteria used and the frequency of use for these criteria in the studies examined as part of the literature review are given in Table 3.

Table 3. *Frequency of use of sustainability criteria*

Criteria	Frequency
Operational & Technical	10
Management	6
Economic	12
Political	4
Cost	5
Quality	4
Technology	2
Environmental	18
Energy	1
Biological	2
Ecological	3
Social	11

3. METHODOLOGY

The aim of this study is to establish supplier portfolios in a defense industry company and to enable sustainable risk assessment with a MCDM method. The importance degree of main criteria and sub-criteria are determined with AHP method and the Ranking method is used to rank the suppliers in terms of risky. For sustainable risk assessment of supplier portfolios, the steps outlined in the flow chart below (Figure 1) are followed.
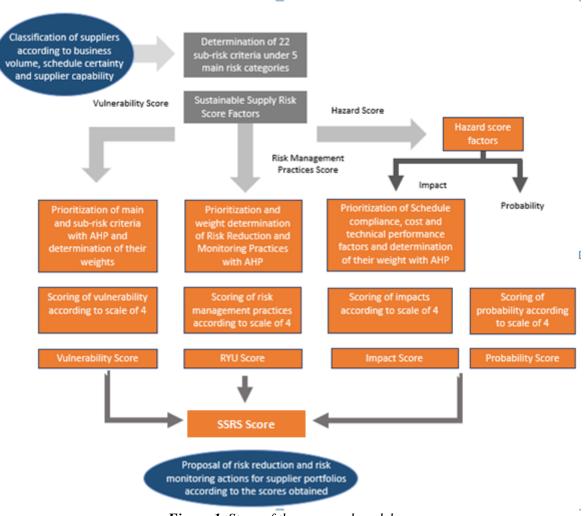

Figure 1. *Steps of the proposed model*

3.1. Determination of Supplier Portfolios

This study is based on the model introduced by Kraljic considering the factors such as supply structure, product variety and market strategies. Business volume, schedule certainty, and supplier's ability are determined as critical factors that affect supply risk by decision makers working in the Enterprise Risk Management and Supply and Material Management departments. According to these criteria, suppliers are classified as in Table 4. In this study, suppliers in categories B, C, F and G are studied in order to take into account the opposite situations in terms of risk.

Table 4. *Risk-based supplier classification matrix*

Business Volume	Low Supplier Capability / High Schedule Certainty	Low Supplier Capability / Low Schedule Certainty	High Supplier Capability / High Schedule Certainty	High Supplier Capability / Low Schedule Certainty
Low	A Category	B Category	C Category	D Category
High	E Category	F Category	G Category	H Category

3.2. Determination of Sustainable Risk Criteria

When studies in the literature are examined, it can be seen that the sustainable risk criteria used differ from the sector. The criteria taken into consideration in this study in the defense industry are determined by reference to both sectoral requirements and studies in the literature. Experienced experts and executive persons from the Corporate Risk Management and Supply and Material Management departments of the company where the study is conducted have been contributed to the determination and classification of sustainable risk criteria (Figure 2).
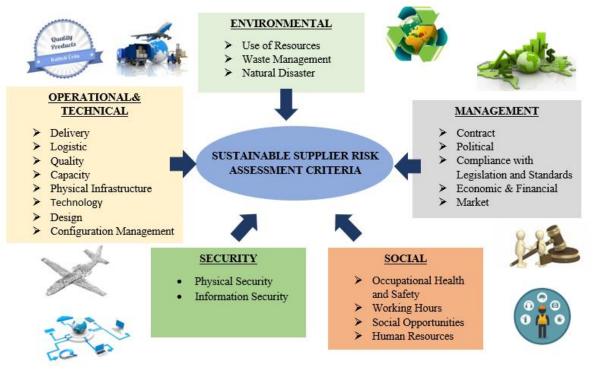

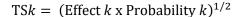***Figure 2.*** *Sustainable supplier risk criteria*

3.3. Sustainable Supplier Risk Assessment Framework

As seen in Figure 1, after determining the main and sub-criteria, the second step is to determine the Total Sustainable Supplier Risk Score (SSRS).

Total Sustainable Supplier Risk Score (SSRS) of suppliers assessed in terms of sustainability criteria is calculated by the subjective evaluation of the levels of hazard, vulnerability and risk management practices for each potential hazard as shown in Equation (1). In the study, the Rating and AHP methods were used together to calculate the scores. The methods used to calculate the value (score) of each factor are described below

SSRS = Hazard Score (HS) x Vulnerability Score (VS) x Risk Management Practices (RMP). (1)

In this study, the level of hazard from certain supply portfolios is evaluated by considering the effects and probabilities. The hazard score is obtained for each *k* hazard as in Equation (2). Figure 3 shows the criteria used for Hazard Assessment.

$$\text{TS}k = (\text{Effect } k \text{ x Probability } k)^{1/2} \qquad (2)$$
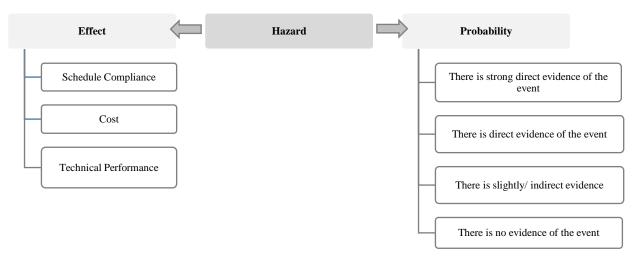

Figure 3. Approach to the determination of the hazard potential

The impact dimension has been assessed by AHP considering the importance given by the decision makers on each impact criteria. The values obtained by the AHP method in the model represent the weights assigned to different business objectives under the impact dimension. The actual impact measurement is achieved by scoring the impact of each potential hazard on each business objective by a 4-point scale, developed by referencing the scale already used in the defense industry company. In this scale, 4 points indicate very high effect, 3 points high effect, 2 medium effect and 1 low effect (Table 5).

It is important to determine the probability of risks in order to prioritize risks that are more likely to occur. In the proposed model, probabilities are scored on a scale of 4 according to the ratings specified in Table 5. The 5-point probability scale proposed by Hallikas et al. was adapted to the scale used by the subject company, as reviewed by decision-makers and managers [47]. The 4-point scale given at the Table 5 is used within this study.

Table 5. Scales used to assess impact and likelihood of risks

Impact on business objectives	Impact Score	Probability of Occurrence	Probability Score
Very High	4	There is strong direct evidence of the event	4
High	3	There is direct evidence of the event	3
Middle	2	There is slightly/ indirect evidence	2
Low	1	There is no evidence of the event	1

Vulnerability is a concept that emerges from human experience to distinguish routine everyday life from extraordinary situations. Vulnerability can be defined as the intrinsic risk factor of the subject or system exposed to a hazard or its susceptibility to damage. In the proposed model, the sensitivity score is measured in three steps:

- First, 5 main risk categories and 22 sub-risk criteria related to the 5 main risk categories were determined by the experts and managers in the Procurement & Material Management and Enterprise Risk Management departments of the subject company, and their weights were determined by AHP method. The weights of the main risk criteria were multiplied by the weight of the sub-risk criteria to obtain the global weights for each risk criterion.
- Then, for measuring the vulnerability score for each supplier portfolio, the 4-point scale used in the subject company was adapted to the study by referencing the study by Ruiz [11] (Table 6).

- Each risk criterion is multiplied by the weights obtained by AHP method to obtain final vulnerability scores.

For each k hazard, Vulnerability Score (VS) is calculated by multiplying the geometric mean of the scores given by each decision maker as shown in Equation (3) with the global risk criterion weight:

$$\text{HS}k = \left(\prod_{i}^{N} Si\right)^{\frac{1}{N}} \times \text{Wnk} \tag{3}$$

n = Main risk criteria
k = Sub-risk criteria
W_{nk} = Global Weight of Sub-Risk Criteria k under main criteria n
i = Decision maker
$i = 1; 2; …; N$
S_i= Vulnerability score given by decision maker; 1: low; 2: middle; 3: high; 4: very high .

Table 6. *Scale used for vulnerability score*

Risk Exposure	Vulnerability Score
Very High	4
High	3
Middle	2
Low	1

Risk management practices are a set of proactive approaches to protect and / or prevent the system from potential hazards and risks. Within the scope of risk management practices, risk monitoring and risk mitigation activities are taken into consideration together with the characteristics of supplier portfolios, with the ultimate aim of long-term supplier development.

Risk Monitoring: Risk monitoring activities include periodic reviews and audits on technical and managerial issues of importance for the defense industry. These activities enable suppliers to be part of a dynamic structure involving continuous learning and improvement.

Risk Mitigation: Risk mitigation strategies in the defense industry include the training of the company's own staff and stakeholders, improvement studies including root-cause analysis for risk mitigation, SWOT analyses, benchmarking and product & process development, and studies, surveys, resource and information-sharing methods to enhance supplier communication and development.

In order to evaluate the level of risk management practices in the proposed model, as shown in Table 7, a 4-point scale has been used for each risk management criterion. In the quantification of risk management practices, the scale used in the subject company has been adapted into the study. Figure 4 illustrates the activities for risk monitoring and mitigation.

$$\text{RMP} = (\text{Risk Monitoring} \times \text{Risk Mitigation})^{1/2} \tag{4}$$

RISK MANAGEMENT PRACTICES	
Risk Monitoring	**Risk Mitigation**
Audit	Training
Management review	Improvement works
	Development of stakeholders

Figure 4. *Risk Management Practices*

Table 7. *Scales used for risk monitoring and risk mitigation*

Risk Monitoring / Risk Mitigation	Risk Management Practice Score
Not available	4
Planning	3
Available but missing	2
Available	1

4. A CASE STUDY AT THE DEFENSE INDUSTRY

In this study, a case study has been applied in a defense industry company following Figure 1 described in section 3. Reasons for the selection of defense industry are as follows:
- No industry-specific study has been conducted in previous literature,
- The company caters to internationally strategic customers,
- Increasing pace on the design and production activities for indigenous products,
- Very low defect tolerance in operations,
- Increasing pace of activities towards the strategy of localizing the suppliers,
- A high number and variety of suppliers directly related to the variety of the company's products and services.

4.1. Sustainable Supplier Risk Assessment

By following steps described in Figure 1, SSRS have been calculated for four supplier portfolios that have a high impact on the sustainability of the company, taking into account the decisions of 8 senior managers from Supply & Materials Management and Enterprise Risk Management departments of the subject company. According to the scores obtained, specific actions-to-take are determined for each supplier portfolio. Actual data obtained via one-to-one interviews with subject company managers as well as previous studies in literature are utilized throughout the studies.

The hazard score of each supplier portfolio is evaluated considering impact and probabilities. While cost was determined as the least important criterion by the decision-makers, technical performance and schedule compliance, respectively, were considered to be more effective on the company's strategic objectives and reputation. Table 8 represents the priority matrix and weights obtained by the decision makers. Final impact and probability scores obtained for all supplier portfolios are summarized in Table 9.

Table 8. *Priority matrix and weights determined by decision makers*

Business Objectives	Schedule compliance	Cost	Technical Performance	Weights
Schedule compliance	1	22/9	4/9	0.300
Cost	2/5	1	1/3	0.156
Technical Performance	9/4	3	1	0.545

Finally, the hazard scores obtained by taking the geometric mean of the effect and probability scores for each supplier portfolio and risk criterion, as previously stated in Equation (2), are shown in Table 9.

According to the vulnerability scores calculated, operational risks are determined to have the highest weight. This is followed by security, management, social and environmental risks, respectively. Vulnerability scores obtained by decision makers as well as the global weight of risk criteria and final sensitivity scores obtained by using Equation (3) are presented in Table 10. As indicated, the highest sensitivity scores emerged in supplier categories F and G, followed by categories B and C. On the basis of the risk criteria, vulnerability scores in physical security and information security are determined to be the highest. This is followed by configuration management, quality, delivery and human resources risks.

Table 9. *Impact, probability and hazard scores for all supplier portfolios*

Risk Categories	Sub-risk Criteria	Impact Score				Probability Score				Hazard Score			
		B	C	F	G	B	C	F	G	B	C	F	G
OPERATIONAL & TECHNICAL	Delivery	0.72	0.57	0.79	0.68	3.06	1.54	3.59	2.21	1.49	0.93	1.68	1.22
	Logistic	0.59	0.50	0.74	0.64	2.77	1.68	3.41	2.03	1.28	0.92	1.58	1.14
	Quality	0.52	0.56	0.73	0.69	3.34	1.71	3.41	2.10	1.32	0.98	1.58	1.21
	Capacity	0.60	0.59	0.77	0.65	1.93	2.00	2.67	2.81	1.08	1.09	1.43	1.35
	Physical Infrastructure	0.52	0.48	0.64	0.60	2.33	1.68	2.67	2.45	1.10	0.90	1.31	1.21
	Technology	0.53	0.59	0.66	0.66	1.89	1.54	2.29	1.93	1.00	0.95	1.23	1.13
	Design	0.47	0.47	0.56	0.55	2.54	1.36	2.54	1.83	1.10	0.80	1.19	1.00
	Configuration	0.54	0.59	0.77	0.69	2.81	1.80	3.02	2.41	1.24	1.03	1.53	1.29
MANAGEMENT	Contract	0.57	0.58	0.66	0.71	1.68	1.80	2.25	2.33	0.98	1.02	1.21	1.29
	Political	0.34	0.42	0.48	0.54	1.68	1.71	2.25	2.33	0.75	0.84	1.04	1.12
	Compliance with Legislation and Standards	0.45	0.47	0.55	0.55	2.03	1.62	2.33	1.71	0.96	0.87	1.13	0.97
	Economic & Financial	0.50	0.45	0.57	0.57	2.29	2.17	2.25	2.14	1.07	0.99	1.13	1.10
	Market	0.53	0.51	0.60	0.56	2.38	2.03	2.45	2.25	1.12	1.01	1.21	1.12
ENVIRONMENTAL	Use of Resources	0.51	0.56	0.62	0.58	2.03	1.54	2.54	2.00	1.02	0.93	1.25	1.08
	Waste Management	0.40	0.37	0.43	0.38	2.25	1.54	2.67	1.54	0.95	0.75	1.08	0.77
	Natural disasters	0.57	0.51	0.71	0.64	1.49	1.41	1.86	1.71	0.92	0.85	1.15	1.05
SOCIAL	Occupational Health and Safety	0.51	0.50	0.59	0.58	2.77	1.83	3.29	2.81	1.19	0.96	1.39	1.28
	Working Hours	0.67	0.68	0.77	0.71	2.18	1.83	2.54	2.18	1.21	1.12	1.40	1.25
	Social Opportunities	0.43	0.42	0.48	0.41	2.29	1.54	2.33	1.68	0.99	0.80	1.05	0.83
	Human Resources	0.58	0.68	0.72	0.72	2.54	2.33	2.96	2.91	1.21	1.26	1.46	1.44
SECURITY	Physical Security	0.43	0.48	0.46	0.53	2.10	2.33	2.41	2.63	0.95	1.06	1.06	1.18
	Information Security	0.36	0.48	0.54	0.57	2.33	2.77	2.67	3.54	0.92	1.15	1.20	1.42

Table 10. *Sensitivity scores for all supplier portfolios*

Risk Categories	Sub-risk Criteria	Vulnerability Score				Global Risk Weights	Weighted Vulnerability Score			
		B	C	F	G		B	C	F	G
OPERATIONAL & TECHNICAL	Delivery	2.18	1.54	3.18	2.96	0.047	0.10	0.07	0.15	0.14
	Logistic	2.00	1.30	2.91	2.71	0.029	0.06	0.04	0.08	0.08
	Quality	2.85	2.03	3.41	2.06	0.066	0.19	0.13	0.23	0.14
	Capacity	2.00	1.54	3.06	2.81	0.038	0.08	0.06	0.12	0.11
	Physical Infrastructure	2.25	1.44	2.67	2.14	0.027	0.06	0.04	0.07	0.06
	Technology	2.25	1.49	2.67	1.80	0.044	0.10	0.07	0.12	0.08
	Design	2.14	1.36	2.67	2.17	0.066	0.14	0.09	0.18	0.14
	Configuration	2.63	1.57	3.41	2.71	0.077	0.20	0.12	0.26	0.21
MANAGEMENT	Contract	1.71	1.57	2.18	2.62	0.047	0.08	0.07	0.10	0.12
	Political	1.19	1.41	1.68	2.67	0.020	0.02	0.03	0.03	0.05
	Compliance with Legislation and Standards	1.80	1.36	2.29	1.86	0.049	0.09	0.07	0.11	0.09
	Economic & Financial	1.68	1.77	2.14	2.71	0.044	0.07	0.08	0.09	0.12
	Market	1.41	1.96	1.80	2.81	0.034	0.05	0.07	0.06	0.09
ENVIRONMENTAL	Use of Resources	2.21	1.49	2.71	2.71	0.037	0.08	0.05	0.10	0.10
	Waste Management	1.86	1.30	2.25	2.03	0.024	0.04	0.03	0.05	0.05
	Natural disasters	1.80	1.49	2.33	2.58	0.012	0.02	0.02	0.03	0.03
SOCIAL	Occupational Health and Safety	2.45	1.83	2.98	2.45	0.042	0.10	0.08	0.12	0.10
	Working Hours	2.25	1.41	2.58	2.03	0.023	0.09	0.06	0.11	0.09
	Social Opportunities	1.30	1.00	1.77	1.68	0.011	0.05	0.04	0.07	0.07
	Human Resources	2.10	2.63	2.33	3.29	0.032	0.09	0.11	0.10	0.14
SECURITY	Physical Security	1.86	2.71	2.81	3.72	0.095	0.18	0.26	0.27	0.35
	Information security	1.86	2.71	2.81	3.72	0.134	0.18	0.26	0.27	0.35

The priority matrix and RMP weights were determined by decision makers (Table 11). Then the weighted RMP score was obtained by multiplying the RMP weights and RMP scores determined by decision makers (Table 11). Final RMP scores were then calculated by taking the geometric mean of risk mitigation and risk monitoring scores from risk management practices with the help of Equation (4) (Table 12). According to these results, the supplier portfolios with lesser capabilities are determined to be lacking in risk mitigation and monitoring activities compared to the supplier portfolios with greater capabilities.

***Table 11.** Weighted Risk Management Practices Scores*

Risk Management Practices		Risk Management Practices Scores				Weights	Weighted Risk Management Practices Scores			
		B	C	F	G		B	C	F	G
Monitoring	Audits	2.21	1.15	1.86	1.15	0.100	0.22	0.11	0.19	0.11
	Management reviews	2.91	1.71	2.77	1.30	0.087	0.25	0.15	0.24	0.11
Mitigation	Trainings	3.22	1.83	3.06	1.54	0.357	1.15	0.66	1.10	0.55
	Improvement works	3.34	2.03	2.96	1.41	0.286	0.96	0.58	0.85	0.40
	Development of stakeholders	3.08	1.93	3.11	1.49	0.169	0.52	0.33	0.53	0.25

***Table 12.** Final Risk Management Practices Scores*

Risk Management Practice	B	C	F	G
Monitoring	0.24	0.13	0.21	0.11
Mitigating	0.83	0.50	0.79	0.38
Risk Management Score	0.44	0.26	0.41	0.21

In the final stage, Sustainable Supplier Risk Scores are obtained as shown in Table 13 with the help of Equation (1). When the combination of the scores obtained for each supplier portfolio is considered, the highest scores have been obtained, as predicted, for F class suppliers – those with lesser capabilities and a lower degree of schedule certainty, albeit with high business volume. This is followed by B class, which has low supplier capability, schedule certainty and business volume. For C and G classes with high supplier capability and schedule certainty, no significant difference in scores have been observed compared to B and F classes.

In terms of risk criteria, risks with the highest scores are observed in the areas of delivery, quality, design, configuration management, occupational health and safety, human resources, physical security and information security. Risks related to logistics, physical infrastructure, technology, contract, economic and financial, legal regulations and compliance with standards, resource usage and working hours are also determined to be worthy of consideration in terms of risk mitigation practices. Other remaining criteria should be kept under control by utilizing risk monitoring practices.

When the risk scores are examined in terms of supplier portfolios, operational risks such as delivery, quality, design and configuration management have been observed to be higher in suppliers of Class B and F because of their supplier capability and calendar specificity status. On the other hand, it has been determined that information security and physical security risks increase in line with supplier capability and business volume. This emphasizes the importance of addressing risks separately for different supplier portfolios.

Table 13. SSRS Score

Risk Categories	Sub-risk Criteria	Hazard Score				Vulnerability Score				Risk Management Practices Scores				Sustainable Supplier Risk Score				Sum
		B	C	F	G	B	C	F	G	B	C	F	G	B	C	F	G	
OPERATIONAL & TECHNICAL	Delivery	1.49	0.93	1.68	1.22	0.10	0.07	0.15	0.14	0.44	0.26	0.41	0.21	0.07	0.02	0.10	0.04	0.22
	Logistic	1.28	0.92	1.58	1.14	0.06	0.04	0.08	0.08	0.44	0.26	0.41	0.21	0.03	0.01	0.05	0.02	0.11
	Quality	1.32	0.98	1.58	1.21	0.19	0.13	0.23	0.14	0.44	0.26	0.41	0.21	0.11	0.03	0.15	0.03	0.32
	Capacity	1.08	1.09	1.43	1.35	0.08	0.06	0.12	0.11	0.44	0.26	0.41	0.21	0.04	0.02	0.07	0.03	0.15
	Physical Infrastructure	1.10	0.90	1.31	1.21	0.06	0.04	0.07	0.06	0.44	0.26	0.41	0.21	0.03	0.01	0.04	0.01	0.09
	Technology	1.00	0.95	1.23	1.13	0.10	0.07	0.12	0.08	0.44	0.26	0.41	0.21	0.04	0.02	0.06	0.02	0.14
	Design	1.10	0.80	1.19	1.00	0.14	0.09	0.18	0.14	0.44	0.26	0.41	0.21	0.07	0.02	0.09	0.03	0.20
	Configuration Management	1.24	1.03	1.53	1.29	0.20	0.12	0.26	0.21	0.44	0.26	0.41	0.21	0.11	0.03	0.16	0.06	0.36
MANAGEMENT	Contract	0.98	1.02	1.21	1.29	0.08	0.07	0.10	0.12	0.44	0.26	0.41	0.21	0.04	0.02	0.05	0.03	0.14
	Political	0.75	0.84	1.04	1.12	0.02	0.03	0.03	0.05	0.44	0.26	0.41	0.21	0.01	0.01	0.01	0.01	0.04
	Compliance with Legislation and Standards	0.96	0.87	1.13	0.97	0.09	0.07	0.11	0.09	0.44	0.26	0.41	0.21	0.04	0.01	0.05	0.02	0.12
	Economic & Financial	1.07	0.99	1.13	1.10	0.07	0.08	0.09	0.12	0.44	0.26	0.41	0.21	0.04	0.02	0.04	0.03	0.13
	Market	1.12	1.01	1.21	1.12	0.05	0.07	0.06	0.09	0.44	0.26	0.41	0.21	0.02	0.02	0.03	0.02	0.09
ENVIRONMENTAL	Use of Resources	1.02	0.93	1.25	1.08	0.08	0.05	0.10	0.10	0.44	0.26	0.41	0.21	0.04	0.01	0.05	0.02	0.12
	Waste Management	0.95	0.75	1.08	0.77	0.04	0.03	0.05	0.05	0.44	0.26	0.41	0.21	0.02	0.01	0.02	0.01	0.06
	Natural disasters	0.92	0.85	1.15	1.05	0.02	0.02	0.03	0.03	0.44	0.26	0.41	0.21	0.01	0.00	0.01	0.01	0.03
SOCIAL	Occupational Health and Safety	1.19	0.96	1.39	1.28	0.10	0.08	0.12	0.10	0.44	0.26	0.41	0.21	0.05	0.02	0.07	0.03	0.17
	Working Hours	1.21	1.12	1.40	1.25	0.09	0.06	0.11	0.09	0.44	0.26	0.41	0.21	0.05	0.02	0.06	0.02	0.15
	Social Opportunities	0.99	0.80	1.05	0.83	0.05	0.04	0.07	0.07	0.44	0.26	0.41	0.21	0.02	0.01	0.03	0.01	0.08
	Human Resources	1.21	1.26	1.46	1.44	0.09	0.11	0.10	0.14	0.44	0.26	0.41	0.21	0.05	0.04	0.06	0.04	0.18
SECURITY	Physical Security	0.95	1.06	1.06	1.18	0.18	0.26	0.27	0.35	0.44	0.26	0.41	0.21	0.07	0.07	0.12	0.09	0.35
	Information security	0.92	1.15	1.20	1.42	0.18	0.26	0.27	0.35	0.44	0.26	0.41	0.21	0.07	0.08	0.13	0.10	0.38

| Sum | | | | | | | | | | | | | | 1.03 | 0.48 | 1.47 | 0.68 | = | 3.65 |
| Average | | | | | | | | | | | | | | 0.05 | 0.02 | 0.07 | 0.03 | = | 0.17 |

5. DISCUSSION AND CONCLUSIONS

Presenting sustainability as an additional dimension of focus in the increasingly competitive conditions increases the complexity of supply chains. However, resources allocated to the implementation of Sustainable Supply Chain Management remain very limited in many organizations. This study aims to reduce the difficulties in sustainability by facilitating the integration and interpretation of large amounts of data on potential supplier risks and risk management practices. At the moment, the study proposes a comprehensive multi-criteria framework for the assessment of sustainable supply risks by incorporating stakeholders' views as well as short and long-term internal and external hazards in the supply chain. Furthermore, this study differentiates from previous studies by contributing to the development of suppliers through focusing on qualitative methods to evaluate supplier risk monitoring and risk mitigation practices. Finally, the methods used in the study differ from other studies in literature in terms of focusing on the

defense industry and incorporating industry requirements in the forming supplier portfolio. The need to address different strategies and risk management practices for the development of supplier portfolios is also considered in the study.

In the study carried out in a defense industry company, suppliers were categorized according to business volume, schedule certainty and capabilities, and a SSRS has been calculated for each supplier portfolio in accordance with the Figure 1 and methodology presented in the related section. The results are analyzed in terms of supplier portfolios, indicating a very high score in Category F which has high business volume, low schedule certainty and lesser capabilities, followed by B and G categories. The risk score obtained for category C confirmed a low level of criticality for these suppliers. Accordingly, risk monitoring activities such as periodic reviews or verification of certificates issued by third parties may be sufficient for suppliers in category C and G, while risk monitoring practices should be supplemented by specific risk mitigation activities for categories F and B with higher SSRS scores. For example, the number, period and scope of the trainings given to these suppliers may be increased by the subject company. Human resources and physical resources may be provided for supplier development. Information-sharing may also be implemented. Communication with suppliers may be improved through surveys, bulletins, interface systems, etc. to identify potential risks. The risks of the suppliers and thus the subject company itself may be reduced by establishing long-term partnership for improvement. In this context, the subject company should lead its suppliers in initiating risk mitigation activities and ensure the continuity of these activities. In terms of risk criteria, it has been observed that risks with the highest score belong to the areas of delivery, quality, design, configuration management, occupational health safety, human resources, physical security and information security. Additionally, logistics, physical infrastructure, technology, contract, economic and financial, legal regulations and compliance with standards, use of resources and working hours were determined to be worthy of consideration for risk mitigation activities. Other remaining criteria should be kept under control with routine risk monitoring practices.

The proposed model is considered to be a useful guideline for measuring possible risks for sustainable supply chain management and facilitating the development of risk monitoring and mitigation strategies. Different matrix structures and methods may be developed by considering industry requirements while forming supplier portfolios in future studies. Industry-based differentiation and determination of more detailed risk criteria, business objectives and vulnerability parameters may be considered in evaluating supplier risks. Additionally, different methods other than AHP may be used in determining the impact weights in the calculation of the risk scores, observing the effect on the performance of the method proposed. The results obtained in this study have been evaluated according to the scores above the arithmetic mean. In future studies, other quantitative solutions such as clustering method may be presented in this phase, and the criticality of risk criteria may be evaluated in a different framework.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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