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RESEARCH PAPER

Identification and Assessment of Critical Risks of Sustainable Supply Chain in the Iranian Lead and Zinc Industry

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ABSTRACT
Sustainability is now increasingly recognized as an effective strategy to deal with the current challenges of global supply chains. Supply chains of the lead and zinc industries are most important. Because these two industries not only are among the high-risk in different countries, including Iran, but also can affect economic, social, and environmental sustainability. On the other hand, identifying and assessing the critical risks of supply chains have been less addressed in recent studies. This study aimed to identify and assess critical risks of sustainable supply chains (SSCs) in the Iranian lead and zinc industry. This study was a mixed-method (qualitative and quantitative) descriptive survey. Based on the literature, 24 risk factors that affect supply chain sustainability were identified, out of which 20 critical risk factors were confirmed in two steps by reviewing experts' comments and the data obtained from in-depth interviews and questionnaires. The validity of questionnaires is verified based on the opinions of a group of 5 experts in the first step and another group of 17 experts and professionals of the lead and zinc industry in the second. The Cronbach's alpha coefficient of the questionnaires was calculated to be 0.837, indicating the reliability of the questionnaires. The risk factors were analyzed using the Risk Priority Number (RPN), fuzzy DEMATEL, and risk matrices. Based on the results, "lack of technological/knowledge sustainability", "price and cost fluctuations", "inflation and exchange rates" and "environmental pollution" were the most important risk factors in the supply chain of the Iranian lead and zinc industry.

KEYWORDS: *Supply chain sustainability; Risk assessment; Environmental pollution; Lead and zinc industry.*

1. Introduction

Industry pioneers of the last decade have emphasized that the main prerequisite for achieving a larger market share is to meet customer demands. Modern organizations pay more attention to customers' needs and try to provide quality products and services accordingly [1]. Facilitating the relationship between customer needs, distribution networks, and internal activities requires a scientific approach [2]. Supply chain management can make it possible for organizations to do that. Also can considerably affect organizational performance, organizational sustainability, and stakeholder satisfaction. Supply chain managers are forced with proper decision-making on sustainable sourcing, developing the internal capabilities, communication management, and asset improvement to reduce sustainability-associated costs and risks [3, 20].

The ever-increasing competition and cooperation of various organizations in various business activities may expose supply chains to events and risks variety. Moreover, the cooperation of supply chain stakeholders in maintaining their long-term profits may exacerbate the negative

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effects of risk factors on parts or the entire supply chain or even increase the vulnerability of an SSC [4, 29]. It can thus be stated that there is a growing trend towards supply chain sustainability and risk management. Moreover, quantitative studies on critical risks have been reviewed due to their impact on the level of supply chain sustainability. Some of these studies have focused solely on environmental risks [13, 20] while others have limited themselves to specific areas [3, 15]. Risk management can be employed throughout the organization in many areas and levels, at any time, and for specific tasks, projects, and activities. Any specific area or any application of risk management has its own needs, audience, perceptions, and criteria. One of the main features of ISO 31000 is that it serves as an activity at the beginning of the general risk management process and creates an environment in which organizations can pursue their goals and record various criteria of risk [4, 8]. Continuous changes in environmental factors and economic systems cause different risks to affect the structure of organizations. Different organizations, including financial institutions and even governments, face certain risks depending on their area of operation. However, quantitative categorizations of risks have also been proposed by researchers. Elkins (2005) categorized the strategic risks of supply chains under financial risks, strategic risks, operational risks, and incidental risks [5, 13]. Turkmen and McCormack (2009) divided supply chain risks into two general categories of internal and external uncertainty. They argued that internal uncertainties are caused by either market or technological turmoil, whereas external uncertainties originate from continuous or discrete risks [6, 9]. Srvulaki and Davis (2010) categorized supply chain risks into environmental and process risks and the process risks into five categories, including operational risks, empowerment risks, financial risks, technological/information processing risks, and integration risks [6, 10]. Hoffman et al. (2014) investigated the processes by which the supply chain items and categories may pose sustainability risks. Xu et al. (2019) developed a framework for assessing supply chain sustainability risks by measuring operational risks, social risks, and environmental risks across the supply chain in order to establish a comprehensive standard. Xu et al. (2013) investigated risk management in SSCs in two categories: simple product and complex product supply chains. They investigated the risks related to each category separately [7, 11].

Few studies have been conducted on identifying the nature of risks related to supply chain sustainability and the proposal of risk management strategies to deal with them. On the other hand, since some risks, such as environmental pollution, fluctuations in global prices of manufactured products, and shortage of the primary and secondary raw material have influenced the Iranian lead and zinc industry, it is necessary to evaluate sustainability risks and propose effective strategies to improve supply chain sustainability in this industry. It is noteworthy that extreme fluctuations in prices and costs as inflation and exchange rates in domestic and global markets have necessitated assessing the various risk factors to maintain and improve sustainability in this industry. Literature reviews are shown that few studies worked on the identification and assessment of critical risks in SSCs in the lead and zinc industries. Therefore, this study aimed to identify and assess critical risks of SSCs in the Iranian lead and zinc industry [8, 12, 17].

This paper is organized as follows sections. In Section Two, we briefly introduce work related to our research as a literature review. Then, section 3 describes the research methodology. In Section Four, we present research findings. Section five devotes to the discussion. Finally, Section six is a summary of this research and explains conclusions.

2. Literature Review

2.1. Risk management in SSCs

As stipulated in ISO 31000 standard, risk management is defined as a set of coordinated organizational activities to guide and control an organization considering the type of risks (ISO 31000 standard). These activities may include plans to respond to, follow up, and monitor the risks [15, 16]. The systematic risk management process is based on the Deming cycle, according to which such the process does not include a single-step algorithm but is repeated several times as the risk management program is improved and updated [10, 11, 12]. Risk management involves contingency planning for the upstream and downstream supply chains [15, 16]. Risk and risk management are among the topics that are raised indirectly in the field of sustainability. In addition to short-term organizational profitability, studies are conducted on sustainability have focused on risk management measures, including production-related working damages, loss of environmental resources, public safety, and employee well-being [35]. Based on the results of previous studies, it can conclude that "sustainable development" should include the concept of safety, which in turn including the protection against environmental threats, generational extinction, climate changes, famines, food shortage, and population growth. Accordingly, organizations can manage the risks associated with such factors in the long run [8, 11, 18]. A risk can generally define as the probability of deviation from a projected output. Risk and risk management are relatively new concepts in the field of supply chain management with different definitions. Zsidisin et al. (2019) define a supply chain risk as the possibility of an event inside a supply chain in a way that affects the provision of customer needs [15, 16]. Supply chain risks may occur as a result of natural disasters [15, 21]; legal obligations [21]; inadequate demand forecasting and failure to coordinate requirements across the supply chain [17]; changes in the price of raw materials (e.g. energy) [13]; poor quality of suppliers and insufficient accuracy in deliveries, and poor performance of an organization and its suppliers in the environmental and social areas, which lead to costly legal actions [15, 16]. An organization's sense of social responsibility is a risk aspect. It can disrupt the reputation of the members of a supply chain whose activities may provoke negative social emotions and dissatisfaction, and even delinquent behaviors that severely jeopardize the reputation of the supply chain altogether [22, 24, 37]. Risk management in an SSC refers to an organization's ability to understand and manage economic, environmental, and social risks in the supply chain [23, 37]. For instance, Hewlett-Packard (HP) investigated its supply chain risks and determined the management risk priorities. The critical risks of HP included geographical location, chemical processes or harmful works, duration of association with HP, commitment to citizens, and globalization [15, 16]. Harmes, Hansen, and Shotger (2012) studied strategic approaches to SSCM, including "evaluation and selection" and "supplier development" in large-sized joint-stock companies. Their results showed that risk-based strategies focus more on the evaluation and selection processes, whereas opportunity-based strategies mainly emphasize supplier development and learning. They also found that German large-sized companies preferred to employ opportunity-based approaches rather than risk-based ones. Risk-based strategies are used when companies have set defensive goals such as risk reduction or brand protection. Another feature of risk-based strategies is that the organizational market departments, such as marketing and R&D, have a non-core relationship with SSCM [26, 33]. Papadopoulo and Giannakis (2015) introduced a new classification of sustainability-related supply chain risks. After an extensive literature review and individual interviews, the first categorized 30 risks in three main dimensions of sustainability (i.e. environmental, social, and economic). They then conducted a large survey on different industrial sectors and two experimental-exploratory case studies on two textile companies to identify and analyze the various dimensions of sustainability-related risks. The results indicated that endogenous environmental risks were the most important type in different industries, and there was a very high correlation between various risks related to sustainability [27, 28, 30]. Table 1 presents the classification proposed by Papadopoulo and Giannakis (2015) based on a literature review (Hoffman et al., 2014; BSR, 2010; Blackburn, 2007; Spedding and Rose, 2007; Anderson, 2005) and individual interviews with selected managers of supply chains [21, 29, 32, 34, 36, 37, 39, 40, 44].

Tab. 1. Sustainability-related risks of supply chains [20, 22]

Factors	Internal	External
Environmental	1- Environmental accidents (e.g. fire and explosion), 2- Pollution (air, water, and soil), 3- Non-compliance with sustainability laws, 4- Emission of greenhouse gases, depletion of the ozone layer, 5- Energy consumption (inefficient energy consumption), 6- Unnecessary and double packaging, 7- Waste of products	1- Natural disasters (e.g. storms, floods, and earthquakes), 2- Water shortage, 3- Heatwave, drought
Social (society)	1- Extraordinary working hours, life-work imbalance, 2- Inadequate wages, 3- Children of labor/forced labor, 4- Discrimination (race, gender, religion, disability, age, political views), 5- Safe and healthy work environments, 6- Exploitative employment policies, 7- Immoral treatment of animals	1- Inclusive (universal), 2- Social instability, 3- Demographic challenges/elderly population
Financial/economic	1- Bribery, 2- False claims/dishonesty, 3- Price fixing accusations, 4- Unreliable claims, 5- Patent infringement (copyright), 6- Tax evasion	1- Sanctions, 2- Lawsuits, 3- Fluctuations in energy prices, 4- Financial crises

Differences between ordinary risk management and sustainability-related risk management activities in different aspects are listed in Table 2.

Tab. 2. Risk management for common and sustainability-related risks [20, 41])

	Common Risks	Sustainability-Related Risks
Risk Identification	Supply chain disturbances (delays, forecast errors, intellectual assets, inventories, capacity, etc.)	Ecosystem degradation, impacts on social values and accountability
Risk Assessment	Based on financial or operational criteria/methods	Inferential (deductive) studies
Strategies for Dealing with Risks	Achieving a mutual understanding of risks in the organization through risk testing and adaptation	Development of a portfolio of strategies for managing all three dimensions of sustainability
Methods for Dealing with Risks	Based on risk management and evaluation and proper business planning	Scenario-based planning and simulation, automatic tracking of failures, automatic repair and recovery
Opportunities for Dealing with Risks	Opportunities to internally improve and enhance the business and overtake the competitors	Competitive advantages and chances for business excellence

According to Papadopoulo and Giannakis (2015), the eight major sustainability-related risks of supply chains include natural disasters, emission of greenhouse gases, children of labor/forced labor, financial crises, bribery accusations, pollution, non-compliance with sustainability laws, and energy consumption. However, since the above-mentioned study was conducting in Southern Europe, the proposed sustainability-related risks are influenced by climate, socioeconomic conditions, and regulations governing the study area. Xu *et al*. (2019) developed a framework for assessing sustainability risks of supply chains by measuring operational, social, and environmental risks across the supply chain in order to establish a comprehensive standard. They categorized the sustainability risks of supply chains under three dimensions elaborated in Table 3.

Tab. 3. Sustainability risks of supply chains [25, 44]

Operational	Supply, process, and demand risks as well as organizational risks
Environmental	Human health, ecosystem quality, deficiencies of resources
Social	Social indicators (global), governance indicators (global)

They employed risk assessment distance analysis to analyze the sustainability risks of supply chains. They also cited two case studies to evaluate the proposed framework. The results showed that the supply chain structure and company size are two main factors affecting supply chain sustainability.

A summary of studies conducted on risk management and SSCs presented in Table 4.

Tab. 4. A summary of studies on risk management and SSCs

Author(s)	Year of Publication	Title	Results	The main contribution
Carter and Rogers	2008	Introducing a Framework for Sustainable Supply Chain Management towards a New Theory	They introduced a theoretical framework for supply chain sustainability that reflects the concept of an SSC. This framework includes four supporting or facilitating factors of SSCM, including risk management, transparency, strategy, and organizational culture. The heart of this conceptualization is Elkington's triple policies: sharing environmental, social, and economic performance.	Framework for Sustainable Supply Chain Management
Dauko and Naoko	2008	Activates and Relationship of SSCM with Other Concepts	They proposed a model to describe SSCM based on which they provided an in-depth description of possible actions to determine different activities in the supply chain considering their sustainable effects.	Model for SSCM
Tutberg and Whitestrak	2010	A Systematic Review of Studies on SSCM	They have been proposing the concept of a supply chain home based on the triple underlying dimensions (environmental, economic, and social performance) as the main elements necessary to keep the supply chain structure in balance. In addition, risk management and compliance management are the foundations of this structure. It is so important to identify and reduce risks to achieve long-term profitability. Guidelines and standards can serve as a starting point for implementing principles and practices of sustainability throughout a supply chain.	Systematic review of models on SSCM
Yakova *et al*.	2011	Introducing a Methodology for Measuring Supply Chain Sustainability	They have been considered five steps for a food supply chain, including farming, food processing, food wholesale, food retail, and food preparation. Then they identified nine indices for each of these steps (a total of 45 indices) and divided them into three categories: environmental (Energy consumption, water consumption, waste), social (employment, wages, and gender), and economic (Labor productivity, market focus, and import dependence).	Model for measuring Supply Chain Sustainability
Boyukozkan and Berkul	2011	Development of an SSC by Integrating Network Analysis Process with an Ideal Planning Approach based on Quality Function Development	They have been identified total cost, economic profit, use of stocks, and inventory management requirements, fuel consumption, emission of greenhouse gases, and generated waste as environmental requirements, and health, safety, and rules and regulations as social requirements. They tested the proposed model in a case study.	SSC model using QFD
Hosseini *et al.*	2012	Introducing a Framework for Measuring SSCM Performance	They proposed a matrix for evaluating a supply chain based on which components of a supply chain were manufacturers, distributors, retailers, and customers. They also included economic, social, and environmental dimensions in their model.	Framework for Measuring SSCM Performance
Yasal	2012	An Integrated Model for Measuring Supply Chain Sustainability	Supply chain sustainability is measured based on economic, social, and environmental performance such a sustainable resources.	Integrated Model for Measuring Supply Chain Sustainability

Author(s)	Year of Publica tion	Title	Results	The main contribution
Kilonen *et al*.	2012	A Model for Measuring Sustainability Performance in a Food Supply Chain based on the Supply Chain Operations Reference Model (SCOR)	Performance indicators included reliability, responsibility, flexibility, sustainability, costs, and assets. The proposed model was tested in a food supply chain.	Model for Measuring Sustainability Performance
Zeilani *et al.*	2012	SSCM in Malaysia	Their experimental findings suggested that SSCM practices could positively affect the performance of SSCs, especially in economic and social dimensions.	SSC review in Malaysia
Harmes, Hansen, and Shotger	2012	SSCM Strategies	They studied two SSCM strategies in large-sized joint-stock companies with an emphasis on supplier management. "Evaluation and selection" of suppliers take risk-based strategies, whereas "supplier development" proposes opportunity-based strategies to manage supply chains of sustainable products. Their findings revealed that German companies employ risk-based SSCM strategies.	SSCM strategies review in large-sized joint-stock companies
Papadopoulo and Giannakis	2015	Supply Chain Sustainability: A Risk Management Approach	They conducted an experimental study to understand how to manage the sustainability risks in an integrated manner. After an extensive literature review and individual interviews, the first categorized 30 risks in three main dimensions of sustainability (i.e. environmental, social, and economic). Then they conducted a survey on different industrial sectors and two experimental-exploratory case studies on two textile companies to identify and analyze the various dimensions of sustainability-related risks.	A Risk Management Approach for Supply Chain Sustainability
Sajjad, Ouj and Toppin	2015	Sustainable Supply Chain Management (SSCM): Incentives and Barriers	They studied incentives and barriers to the adaption of SSCM in New Zealand businesses to increase participation in promoting understanding of the incentives and barriers associated with SSCM adoption. To this end, senior executives of four major companies in New Zealand in an exploratory case study. The results demonstrated that the sustainability values of senior management, desire for risk management, and stakeholder management are latent incentives of SSCM adoption. By contrast, poor awareness of suppliers, negative perceptions, and insufficient governmental support was identified as barriers to SSCM adoption.	SSCM review in New Zealand businesses
Chi Koo *et al.*	2017	Investigation of Factors Affecting SSCs (Case study: two countries)	They conducted a study to determine the factors affecting SSCM practices from practical and conceptual perspectives. A questionnaire on SSCM was designed to assess the factors affecting and natural effects of SSCM adoption in Taiwan and Vietnam. In this study, five factors identified that affecting the SSCM. Following the development of a conceptual model for SSCM in practice, a questionnaire related to SSCM was designed to validate the model structure and the five factors affecting the model. They aimed to 1) verify factors affecting SSCM adoption in practice and 2) determine the differences between these two Asian countries.	Investigation of Factors Affecting SSCm
Vargas *et al.*	2018	SSCM Enablers and their Effects on Competitive Advantage in Colombia	It is studied the structures of supply chain social practices, including labor practices, product accountability, social relationships, social responsiveness, and structures of supply chain environmental practices, including green production, ecological design, green logistics, green purchasing, environmental cooperation with customers, and reverse logistics. The results showed that there was a positive relationship between the factors, except for the relationship between environmental practices of the supply chain and competitive advantages.	SSCM review in Colombia
Tseng *et al*.	2018	Development of a Decision-Making Model for SSC Financing under Uncertain Conditions	The study results indicated that social and economic (financial) aspects are stronger than and affect environmental features in SSC financing. Therefore, economic growth and fulfillment of social expectations should be among the top priorities in the integration of supply chain financing with sustainable development. When these two aspects (economic and social) improved to an acceptable level, environmental aspects will improve automatically.	Decision-Making Model for SSC
Hu *et al*.	2019	A Coordinated Strategy for SSCM	The study findings demonstrated that subsidies are necessary to promote product sustainability, and supply chain profit-sharing rate significantly affects product (production) sustainability outcomes, environmental performance, subsidies, and incentives. Moreover, the highest level of product sustainability, environmental performance, supplier profit, central company profit, and subsidy-based supply chain profit was observed when the central company received the highest profit. The results also showed that incentives and subsidies exhibited great effects in all four case studies.	A Coordinated Strategy for SSCM
Xu et al.	2019	Risk Management and Evaluation of Supply Chain Sustainability	The results showed that supply chain structure and company size are two main factors affecting the SSCM decisions.	Risk Management and Evaluation of SSCM
Ponte et al.	2020	Quantifying the Bullwhip Effect in closed-loop supply chains: The interplay of information transparencies, return rates, and lead times	The study stated that the effect of rate of return and unemployment time on system performance strongly depends on the degree of visibility of the supply chain. This perspective allows researchers to review the distinction between previous works. Then the research went from an operational perspective to an economic perspective. In this section, researchers prove that there is an optimal interval rate. It is shown that the optimal rate depends on the cost structure of the time of unemployment and demand variability. The properties of different	Bullwhip Effect in closed-loop supply chains

Author(s)	Year of Publication	Title	Results	The main contribution
			closed-loop systems and management concepts are presented.	
Osadchiy et al.	2021	The bullwhip effect in supply networks	This study seeks to investigate the effect of the phenomenon of leather whipping on environmental performance using increasing pollution emissions and consumption of natural resources. This article compares the modifiers and causes of the whipping effect in direct and closed-loop supply chains. The results show that the causes of the whipping effect in closed-loop supply chains are similar to the causes of this phenomenon in direct or forward supply chains. But most research has not considered that the quality of returned products is different from the quality of non-return products, and adding another variable to the complexity of a supply chain can lead to high variability, which causes a whipping effect.	bullwhip effect in supply networks
Ali et al.	2020	A Discrete Event Simulation Analysis of the Bullwhip Effect in a Multi-Product and Multi-Echelon Supply Chain of Fast Moving Consumer Goods	Investigates the effect of random unemployment time due to leather whipping in a multi-tiered multi-product supply chain under two information-sharing strategies. This effect was measured using a discrete event simulation approach. The results show that the effect of the leather whip can not be removed but can be reduced by sharing focused information. All analyzes help professionals understand the level of impact of demand-sharing information on supply chain performance when unemployment is random.	Bullwhip Effect in a Multi-Product and Multi-Echelon Supply Chain
Present research	Present	Identification and Assessment of Critical Risks of Sustainable Supply Chain in the Iranian Lead and Zinc Industry	This study aimed to identify and assess critical risks of sustainable supply chains (SSCs) in the Iranian lead and zinc industry. It was a mixed-method (qualitative and quantitative) descriptive survey. Based on the literature, 24 risk factors that affect supply chain sustainability were identified, out of which 20 critical risk factors were confirmed in two steps by reviewing experts' comments and the data obtained from in-depth interviews and questionnaires. The validity of questionnaires is verified based on the opinions of a group of 5 experts in the first step and another group of 17 experts and professionals of the lead and zinc industry in the second.	Assessment of Critical Risks of Sustainable Supply Chain

2.2. Critical risks of SSCs

The most important risk factors affecting SSCs (24 risk factors) were initially extracted and categorized under operational, economic, environmental, and social risks based on the literature review (Table 5).

Tab. 5. Risk factors affecting SSC initially extracted from previous studies

Risk factors	Description
Operational Risk Factors[11, 23, 43]	
RF1: Uncertainty of supply and demand [3, 9, 20]	Incorrect forecast of demand or unexpected demand, uncertainty due to intense market competition, under- or over-capacity utilization, and capacity inflexibility
RF2: Failure to select the right suppliers [6, 14, 18, 20]	Failure to select suppliers with better sustainability performance in line with economic, social, and environmental goals
RF3: Poor accountability [11, 34]	Failure to respond quickly and reasonably to demand changes (volume, combination, and place)
RF4: Inflexibility of supply resources [18, 20, 22]	Inflexibility of suppliers in the face of environmental changes (including inflexible capacity)
RF5: Poor efficiency of supply processes [38, 44, 47]	Failure to determine, monitor, and reduce the supply chain breakdowns in production or deliver
RF6: Coordination Complexity [41, 42]	Extraordinary coordination responsibilities due to information distortion, different goals of SSC members, and disputes between partners
RF7: Information technology (IT) risks [22, 26]	Lack of necessary IT infrastructure and mechanisms to promptly receive and disseminate information among members of a supply chain
RF8: Lack of technological/knowledge sustainability [11, 18, 37]	Partners' low awareness and understanding of technology, operations, and sustainable methods

Risk factors	Description
RF9: Human nature/culture [20, 23, 29]	Extent/nature/culture of intellectual and operational risk-taking among individuals
RF10: Business Plan [20, 28, 35]	How organizational plans and projects are implemented can be a source of risk.
Economic Risk Factors [12, 20, 46, 47]	
RF11: Price and cost fluctuations [11, 20, 23, 44, 47]	Fluctuating cost and price (i.e. environmentally friendly raw materials, design, purchases, resources, manufacturing) that cannot guarantee reliable quality and timely deliver
RF12: Inflation and exchange rates [18, 22, 29, 33, 41]	Fluctuating inflation and exchange rates may affect financial considerations and SSC efficiency
RF13: Declining market share [19, 29, 38, 41]	Declining market share due to internal and external reasons (e.g. competition and poor quality)
RF14: Brand/reputation weakening [6, 7, 20, 26]	If customers do not take an organization as a possible source to meet their needs, the organization's credibility and reputation may be jeopardized.
RF15: Errors [13, 19, 22]	Human, mechanical or methodological errors
Environmental Risk Factors [20, 28, 35, 45]	
RF16: Natural disasters [23, 28, 33, 39]	Rare but serious damages caused by natural disasters (e.g. storms, floods, tornadoes, earthquakes)
RF17: Inefficient utilization of resources [13, 21, 28]	Inefficient resources (e.g. energy and renewable waste) are used to produce and deliver goods and services.
RF18: Environmental Pollution [38, 44, 47]	Air, water, soil, or other types of pollution caused by equipment or manufacturing operations
RF19: Generation of hazardous waste [12, 21, 39, 44]	Unused and unwanted materials or goods produced during or as a result of the production or distribution processes
Social Risk Factors [20, 37, 43]	
RF20: Unhealthy/hazardous work environment [3, 8, 12, 20]	Unsafe operations in an unsafe workplace/Use of hazardous substances that threaten the health and safety of employees
RF21: Human rights violations [17, 27, 36, 42]	Behaviors that violate the dignity of or humiliate people, such as recruitment of forced labor or children, discrimination, and long working hours beyond legal requirements
RF22: Poor fulfillment of social obligations [33, 29, 43, 45]	Non-involvement in local technological, cultural, educational, and social development, job creation, health care, and social investment
RF23: violation of business ethics [24, 28, 39, 40]	Behaviors non-compliant with business ethics such as corruption, unfair trade, and invasion of privacy
RF24: Regulations [20, 26, 29, 38]	Laws/Regulations/Bylaws

3. Research Methodology

This study was a mixed-method (qualitative and quantitative) descriptive survey. Experts' views and opinions are elicited in two quantitative and qualitative phases to identify and assess critical risks of a sustainable supply chain in the Iranian lead and zinc industry. The qualitative phase consisted of two steps. First, in-depth interviews (Delphi method) conducted with five experts who were selected non-randomly and judgmentally commensurate with the activities of Iranian lead and zinc companies from among senior organizational managers (CEOs or strategic directors) graduated from a relevant field of study (management) with at least ten years of work experience. More interviews conducted in the second step, this time with 17 experts, including the five who participated in the first step, who were selected non-randomly and judgmentally commensurate with the activities of Iranian lead and zinc companies from among senior and middle organizational managers specialized in the supply chain, risk management, and decision-making. Based on the data collected through questionnaires (views and comments of academic and industrial experts) in this step, the initially identified twenty-four risk factors investigated through literature review and structured interviews, and twenty risk factors were eventually confirmed. Construct validity of supply chain sustainability risks was assessed and confirmed, as shown in Table 6.

This study used the depth study method to review the literature for extracting initial critical risk factors. The field study (interview and questionnaire) method was then employed for final confirming the risk factors and assessing their validity and reliability, as well as collecting and structurally testing the data required for analyzing critical risks of SSCs. The questionnaires were scored based on a 5-point Likert scale. A questionnaire on the "risk factors affecting supply chain sustainability" was used for the final verification of risk factors, construct validity assessment, and structural testing. Another questionnaire was employed to elicit experts' views on various topics such as the impact of risk factors on sustainability (temporal, financial, and functional), the impact of risk, risk probability, and risk detectability. The third questionnaire was used to evaluate the interaction of risk factors. The second and third questionnaires were filled out during specialized interviews with eight experts in the Iranian lead and zinc industry.

The content validity of questionnaires was assessed in two steps. First, five experts of the Iranian lead and zinc industry, who were familiar with concepts of supply chain and risk management, were invited to evaluate the content validity of questionnaires. The outcomes were used to make necessary changes to questionnaires to further modify and validate them. In the second step, the content validity of questionnaires was verified based on the comments of 17 experts in this industry on the modified questionnaires. The views and comments of the same five experts were elicited to assess the face validity of the questionnaires. As a result, the items were modified to formulate the same concept the authors intended. The reliability of the questionnaires was also confirmed by analyzing the data obtained from the 181 retuned questionnaires in SPSS. Cronbach's alpha coefficient of the risk factors is shown in Table 7.

Tab. 6. Results of questionnaire validity assessment

Concept	Category	Indicators	Mean Responses
Risk Factors	Operational	Uncertainty of Supply and Demand	7.1
		Failure to select the Right Suppliers	5.6
		Poor Accountability	6.5
		Inflexibility of Supply Resources	6.9
		Poor Efficiency of Supply Process	6.4
		Coordination Complexity	6.9
		Information Technology (IT) Risks	7.1
		Lack of Technological/Knowledge Sustainability	6.2
	Economic	Price and Cost Fluctuations	7.1
		Inflation and Exchange Rates	7.7
		Declining Market Share	6.4
		Brand/Reputation Weakening	6
	Environmental	Natural Disasters	4.7
		Inefficient Utilization of Resources	6.4
		Environmental Pollution	6.6
		Generation of Hazardous Waste	6.3
	Social	Unhealthy/Hazardous Work Environment	6.8
		Human Rights Violations	5.5
		Poor Fulfillment of Social Obligations	6.1
		Violation of Business Ethics	5.6

Tab. 7. Results of assessing reliability of the research questionnaires

Concept	Categories	Number of Items	Number of Data	Cronbach's Alpha	Total Cronbach's Alpha
Risk factors	Operational Risk Factors	8	181	0.738	0.837
	Economic Risk Factors	4	181	0.712	
	Environmental Risk Factors	4	181	0.775	
	Social Risk Factors	4	181	0.689	

Tab. 8. Composite reliability of the research variables

Variable	Composite Reliability (p Delvin-Goldstein)	Result
Social Risk Factors	0.834	Acceptable
Economic Risk Factors	0.766	Acceptable
Environmental Risk Factors	0.781	Acceptable
Operational Risk Factors	0.785	Acceptable

As Table 7 demonstrates, Cronbach's alpha coefficient of most indices is over 0.7, indicating the reliability of the survey tool. Cronbach's alpha coefficient of social risk factors (0.689) is also considered acceptable because it is close to 0.7. Table 8 presents the results of assessing composite reliability (p Delvin-Goldstein) of the risk factors.
Since the composite reliability of all research variables is over 0.7, it can be stated that they are reliable. The results related to the average variance extracted (AVE) shown in Table 9.

Tab. 9. Convergent validity of the research variables

Variable	Convergent validity (AVE)	Result
Social risk factors	0.558	Acceptable
Economic risk factors	0.462	Relatively Acceptable
Environmental risk factors	0.576	Acceptable
Operational risk factors	0.522	Acceptable

Table 9 shows the convergence validity of the research variables. Since the AVE of most variables is close to 0.5, the convergent validity of all research variables was confirmed.
The data collected in the structural testing were analyzed by using factor analysis in Smart-PLS. In addition, the risk factors were analyzed using the Risk Priority Number (RPN), fuzzy DEMATEL, and risk matrices in Excel. All descriptive analyses were also performed in SPSS.

4. Research Findings

4.1. Descriptive statistics

The results of the descriptive statistics showed that all members of the qualitative sample (100%) were men. In addition, 17.65%, 47.06%, and 35.29% of them aged under 35 years, 35-45 years, and over 45 years, respectively. In terms of educational attainment, 29.42%, 58.82%, and 11.76% of participants had Ph.D., master's degrees, and bachelor's degrees, respectively. The statistics also showed that most participants had a master's degree. Moreover, 35.29%, 29.42%, and 35.29% of participants had a work experience of under ten years, 10-20 years, and over 20 years, respectively, while 35.29% had the highest organizational executive position (CEO or member of the board of directors) and 64.71% were middle managers in the Iranian lead and zinc industry. It is noteworthy that 41.18% of participants were professors in the field of management and the lead and zinc industry, in addition to having organizational positions. The risk factors of SSCs were initially identified and then were included in a questionnaire to be evaluated and scored by the selected 17 experts. Based on experts' views and comments, risk factors with a geometric mean of smaller than 4.5 were eliminated.

Tab. 10. The scores given to risk factors identified by experts

Risk Factors	Expert																	Geometric Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Operational Risk Factors																		
RF1: Uncertainty of supply and	9	9	7	9	7	9	5	7	7	3	9	5	7	9	9	7	7	7.1
RF2: Failure to select the right	7	7	5	5	5	7	7	5	7	3	5	7	5	3	7	7	7	5.6
RF3: Poor accountability	7	7	7	7	5	7	5	9	7	3	7	9	7	7	7	5	7	6.5
RF4: Inflexibility of supply resources	9	9	9	5	7	5	7	7	9	7	7	9	5	7	9	5	5	6.9
RF5: Poor efficiency of supply process	5	5	9	9	7	7	7	3	7	7	9	9	9	5	5	5	5	6.4
RF6: Coordination complexity	7	9	9	7	7	5	7	7	9	9	5	9	9	7	3	7	5	6.9
RF7: Information technology (IT) risks	9	7	9	9	9	5	7	5	9	7	5	5	7	7	7	7	9	7.1
RF8: Lack of technological/knowledge sustainability	7	7	7	7	7	7	5	1	9	7	5	9	9	9	9	5	5	6.2
RF9: Human/cultural nature	3	5	5	7	5	5	5	7	5	5	5	3	3	3	7	5	3	4.3
RF10: Business plan	3	5	5	5	5	7	3	5	5	3	5	3	3	3	5	5	3	4.1
Economic Risk Factors																		
RF11: Price and cost fluctuations	7	9	9	3	5	9	7	7	9	7	7	7	9	9	7	7	7	7.1
RF12: Inflation and exchange rates	7	7	9	9	7	9	7	5	9	5	9	9	9	9	9	7	7	7.7
RF13: Declining market share	9	7	7	7	7	7	5	9	9	3	9	3	9	5	9	5	5	6.4
RF14: Brand/reputation weakening	9	9	7	5	9	3	7	7	9	3	5	5	5	7	5	7	5	6.0
RF15: Errors	7	5	5	5	3	3	5	3	5	5	5	5	3	5	5	3	5	4.4
Environmental Risk Factors																		
RF16: Natural disasters	9	5	7	3	7	3	5	1	7	3	9	3	7	5	5	5	5	4.7
RF17: Inefficient utilization of resources	7	9	7	5	7	3	5	5	9	5	7	7	7	9	7	7	5	6.3
RF18: Environmental pollution	9	9	9	5	5	3	5	7	9	7	7	7	9	9	9	5	5	6.6
RF19: Generation of hazardous waste	5	7	9	5	7	3	5	9	7	3	7	9	9	9	7	5	5	6.2
Social Risk Factors																		
RF20: Unhealthy/hazardous work environment	9	7	5	7	7	3	7	9	7	7	7	5	9	7	9	7	7	6.8
RF21: Human rights violations	7	7	5	7	7	3	7	5	7	3	7	7	5	5	5	5	5	5.5
RF22: Poor fulfillment of social obligations	9	7	7	7	9	3	7	5	9	3	7	5	7	9	5	5	5	6.1
RF23: violation of business ethics	7	9	5	7	5	7	7	5	9	3	7	3	5	5	5	5	5	5.6
RF24: Regulations	5	3	5	3	5	5	5	5	3	5	3	5	3	3	3	5	3	3.9

In this stage, four previously identified risk factors including "human/cultural nature," "business plan," "errors," and "regulations" were excluded from the list of SSC risk factors. Table 11 presents the final list of SSC risk factors.

Tab. 11. Final risk factors of SSCs

General Categories	Risk Factors	Code
Operational Risk Factors	Uncertainty of Supply and Demand	RF1
	Failure to select the Right Suppliers	RF2
	Poor Accountability	RF3
	Inflexibility of Supply Resources	RF4
	Poor Efficiency of Supply Process	RF5
	Coordination Complexity	RF6
	Information Technology (IT) Risks	RF7
	Lack of Technological/Knowledge Sustainability	RF8
Economic Risk Factors	Price and Cost Fluctuations	RF9
	Inflation and Exchange Rates	RF10
	Declining Market Share	RF11
	Brand/Reputation Weakening	RF12
Environmental Risk Factors	Natural Disasters	RF13
	Inefficient Utilization of Resources	RF14
	Environmental Pollution	RF15
	Generation of Hazardous Waste	RF16
Social Risk Factors	Unhealthy/Hazardous Work Environment	RF17
	Human Rights Violations	RF18
	Poor Fulfillment of Social Obligations	RF19
	Violation of Business Ethics	RF20

4.2. Confirmatory factor analysis

First, the normal distribution of the research variables was examined through the Kolmogorov-Smirnov (Table 12).

Tab. 12. Results of the kolmogorov-smirnov Ttest

Variables	Kolmogorov-Smirnov (Z-value)	P-value
Operational Risk Factors	1.19	0.118
Economic Risk Factors	1.27	0.08
Environmental Risk Factors	1.459	0.028
Social Risk Factors	1.565	0.015

Since the significance level of the Kolmogorov-Smirnov test for all four types of risk factors is higher than 0.05, it can be concluded that the data distribution of these variables is not significantly different from a normal distribution. Figure 1 shows the model of relationships between the risk factors.

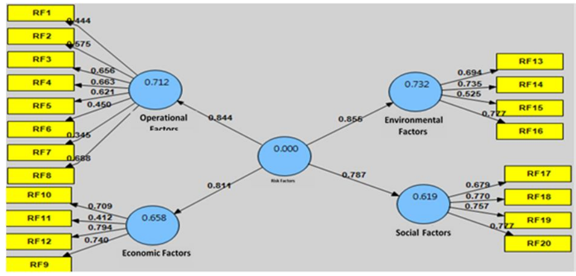

Fig. 1. Intensity of the Relationship between Risk Factors

The significance level of these relationships is presented in Figure 2.

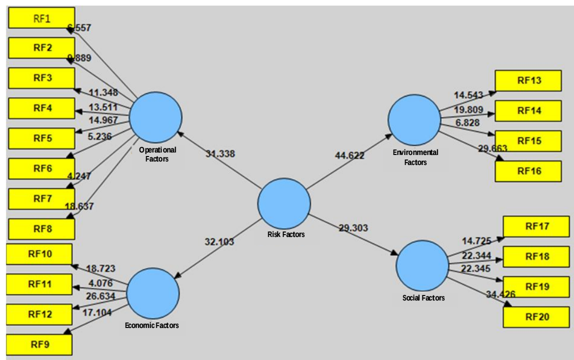

Fig. 2. Significance Level of Risk Factors

The results of testing the structural model are as follows:

1- **Significance Values (T-values):** Values greater than 1.96 indicate the accuracy of the relationship between the constructs and thus confirm the research model at a 95% confidence level.
2- **R^2:** Since R^2 of operational (0.712), economic (0.658), environmental (0.732), and social (0.619) risk factors are at a relatively moderate level, it can be stated that the research model is at a moderate level in terms of structural fit.
3- **Q^2:** Q^2 values of 0.02, 0.15, and 0.25 indicate poor, moderate, and strong predictability, respectively. Since Q^2 is more than 0.25 for all dependent variables, it can be stated that the structural model has an acceptable level of predictability.

The results of evaluating the model's goodness of fit (GOF) are as follows:

Goodness of fit (GOF): GOF values of 0.01, 0.25, and 0.35 indicate poor, moderate, and strong overall fit of the model, respectively. GOF value for the research model was obtained using the following equation:

$$GOF = \sqrt{\overline{communality} \times \overline{R^2}}, \quad (1)$$

Since GOF is equal to 0.412 for risk factors and 0.419 for the input and output factor, it can be concluded that the overall fit of the model was strong and acceptable.

4.3. Ranking the risk factors using fuzzy DEMATEL

In order to weight the 20 risk factors, the opinions of a group of eight experts (the third group of experts) were elicited and analyzed based on fuzzy DEMATEL by using the third questionnaire. Figure 3 shows the importance and interactions between risk factors. The horizontal axis represents the significance of the risk factor and the vertical axis denotes its impact on others.

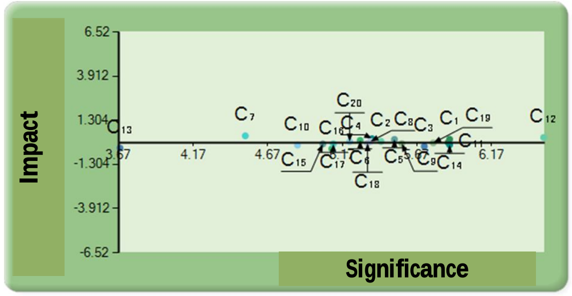

Fig. 3. Interactions between Risk Factors

4.4. Critical risks of SSCs

The statistical description of the 20 risk factors of SSCs based on the data obtained from the questionnaires of risk factors affecting supply chain sustainability.

Tab. 13. Descriptive analysis of the data of risk factors

Code	Risk factor	Temporal Impact of Risk Factors			Financial Impact of Risk Factors			Functional Impact of Risk Factors			Probability of Risk Factors			Detectability of Risk Factors		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
RF1	Uncertainty of Supply and Demand	2.35	5.00	2.00	2.30	4.80	1.00	1.47	4.50	1.50	3.35	3.63	2.67	4.07	4.50	3.80
RF2	Failure to select the Right Suppliers	1.63	5.00	1.50	2.27	4.67	1.00	2.36	4.50	2.00	2.32	2.67	1.67	3.86	4.33	2.7
RF3	Poor Accountability	1.51	4.50	1.00	1.09	4.00	2.00	1.74	3.50	2.00	2.81	4.50	2.00	2.74	3.50	2.50
RF4	Inflexibility of Supply Resources	1.00	4.00	1.00	1.82	4.00	1.00	1.98	4.00	1.00	3.34	3.75	2.67	2.68	3.00	2.33
RF5	Poor Efficiency of Supply Process	0.83	5.00	2.00	1.62	3.60	1.00	2.42	4.50	1.00	3.33	4.33	2.50	3.33	4.33	2.50
RF6	Coordination Complexity	1.25	4.00	1.67	1.79	4.25	1.00	1.79	3.20	1.00	2.56	3.00	2.00	3.15	4.00	2.00
RF7	Information Technology (IT) Risks	1.52	3.67	1.00	1.38	3.50	1.00	1.87	3.00	1.00	3.01	4.00	2.25	2.61	3.67	1.33
RF8	Lack of technological/knowledge sustainability	1.87	4.00	1.50	2.78	4.50	1.33	2.67	4.20	2.00	4.02	4.60	3.67	3.22	3.60	2.60
RF9	Price and Cost Fluctuations	1.52	5.00	1.33	2.87	4.83	1.80	2.50	5.00	2.83	4.23	4.63	3.80	3.74	4.00	3.40
RF10	Inflation and Exchange Rates	2.09	5.00	1.50	2.86	5.00	2.00	2.55	5.00	1.00	4.24	4.75	3.67	2.61	3.33	2.17
RF11	Declining Market Share	1.83	4.50	2.00	1.90	5.00	1.00	2.17	4.00	2.00	3.09	3.60	2.50	3.10	3.50	2.40
RF12	Brand/Reputation Weakening	1.13	4.50	2.67	2.23	4.33	1.00	1.72	4.00	1.00	2.58	3.25	1.50	3.19	4.00	1.50
RF13	Natural Disasters	1.55	4.00	1.00	2.75	4.67	200	2.49	4.00	2.33	2.00	2.20	1.71	1.65	2.00	1.40
RF14	Inefficient Utilization of Resources	1.74	4.00	1.50	2.31	4.50	3.00	1.90	4.33	1.00	2.98	3.67	2.00	2.66	3.20	2.00
RF15	Environmental Pollution	2.11	5.00	1.00	3.31	5.00	2.20	2.20	4.67	1.00	4.29	4.50	4.00	3.86	4.13	3.57
RF16	Generation of Hazardous Waste	2.51	4.00	2.00	2.53	5.00	2.33	1.93	4.25	3.00	2.97	3.43	2.25	2.96	3.43	2.00
RF17	Unhealthy/Hazardous Work Environment	2.10	5.00	1.00	2.36	4.50	1.50	2.57	5.00	2.50	3.09	3.88	1.50	3.46	4.00	2.75
RF18	Human Rights Violations	2.08	5.00	1.00	1.81	3.67	1.00	1.75	3.00	2.00	2.28	2.63	2.00	2.93	3.50	2.20
RF19	Poor Fulfillment of Social Obligations	2.15	4.00	1.00	0.88	3.00	1.00	1.46	4.00	2.00	1.86	2.50	1.00	2.33	3.00	1.80
RF20	Violation of Business Ethics	2.35	5.00	2.00	1.62	3.50	1.00	2.09	4.50	2.00	2.35	2.67	2.20	2.60	3.14	2.00

Considering the mean values presented in Table 13, experts believed that generation of hazardous waste (RF16), the uncertainty of supply and demand (RF1), and poor fulfillment of social obligations (RF15), with means of 2.51, 2.35, and 2.15, respectively, have the highest temporal impact on supply chain sustainability in the lead and zinc industry. Furthermore, poor efficiency of supply process (RF5), inflexibility of supply resources (RF4), and brand/reputation weakening (RF12), with means of 0.83, 1.00, and 1.13, respectively, have the lowest temporal impact on supply chain sustainability in this industry.

According to Table 13, the experts believed that price and cost fluctuations (RF9), inflation and exchange rates (RF10), and lack of technological/knowledge sustainability (RF8), with means of 2.87, 2.86, and 2.78, respectively, have the greatest financial impact on supply chain sustainability in the lead and zinc industry. On the other hand, poor fulfillment of social obligations (RF15), poor accountability (RF3), and information technology (IT) risks (RF7), with means of 0.88, 1.09, and 1.38, respectively, have the lowest financial impact on supply chain sustainability in this industry.

Considering the mean values presented in Table 15, the experts believed that lack of technological/knowledge sustainability (RF8), unhealthy/hazardous work environment (RF17), and inflation and exchange rates (RF10), with means of 2.67, 2.57, and 2.55, respectively, have the highest functional impact on supply chain sustainability in the lead and zinc industry. In addition, poor fulfillment of social obligations (RF19), the uncertainty of supply and demand (RF1), and brand/reputation weakening (RF12), with means of 1.46, 1.47, and 1.72, respectively, have the lowest functional impact on supply chain sustainability in this industry.

According to Table 13, the experts believed that environmental pollution (RF15), inflation and exchange rates (RF10), and price and cost fluctuations (RF9), with means of 4.29, 4.24, and 4.23, respectively, were the most probable risks factors of SSCs in the lead and zinc industry. Moreover, poor fulfillment of social obligations (RF19), natural disasters (RF13), and human rights violation (RF18), with means of 0.88, 1.09, and 1.38, respectively, were the least probable risks factors of SSCs in this industry.

Considering the mean values presented in table 13, it can be concluded that the experts believed uncertainty of supply and demand (RF1), failure to select the right suppliers (RF2), and environmental pollution (RF15), with a mean of 4.07, 3.86, and 3.86, respectively, were the most detectable risk factors of SSCs in the lead and zinc industry. In addition, the least detectable risk factors of SSCs in this industry were natural disasters (RF13), poor fulfillment of social obligations (RF19), and violation of business ethics (RF20), with a mean of 1.65, 2.33, and 2.60, respectively.

4.5.Quantitative analysis of critical risks

In this step, the total impact and probability of each risk factor was extracted. The values obtained for these two variables are presented in Figure 4.

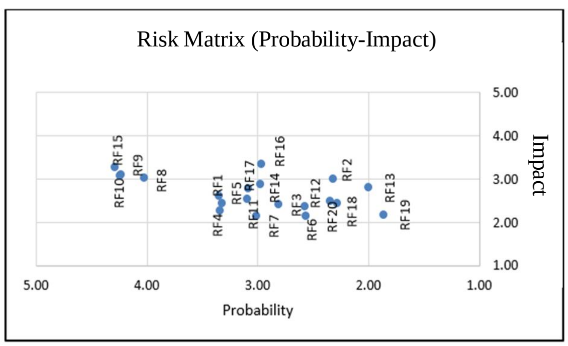

Fig. 4. Risk matrix (probability-impact)

Table 14 presents the status of each risk factor based on the values provided in Figure 4.

Tab. 14. Analysis of risk matrix

Code	Risk Factor	probability-impact			probability-detectability		
		Probability	Impact	Risk Status	Probability	Detectability	Risk Status
RF1	Uncertainty of Supply and Demand	3.35	2.59	Medium	3.35	3.35	Medium
RF2	Failure to select the Right Suppliers	2.32	2.99	Medium	2.32	2.32	Medium
RF3	Poor Accountability	2.81	2.40	Medium	2.81	2.81	Medium
RF4	Inflexibility of Supply Resources	3.34	2.26	Medium	3.34	3.34	High
RF5	Poor Efficiency of Supply Process	3.33	2.43	Medium	3.33	3.33	Medium
RF6	Coordination Complexity	2.56	2.15	Medium	2.56	2.56	Medium
RF7	Information Technology (IT) Risks	3.01	2.14	Medium	3.01	3.01	High

Code	Risk Factor	probability-impact			probability-detectability		
		Probability	Impact	Risk Status	Probability	Detectability	Risk Status
RF8	Lack of Technological/Knowledge Sustainability	4.02	3.03	High	4.02	4.02	High
RF9	Price and Cost Fluctuations	4.23	3.10	High	4.23	4.23	High
RF10	Inflation and Exchange Rates	4.24	3.07	High	4.24	4.24	High
RF11	Declining Market Share	3.09	2.53	Medium	3.09	3.09	Medium
RF12	Brand/Reputation Weakening	2.58	2.37	Medium	2.58	2.58	Medium
RF13	Natural Disasters	2.00	2.80	Low	2.00	2.00	Medium
RF14	Inefficient Utilization of Resources	2.98	2.88	Medium	2.98	2.98	Medium
RF15	Environmental Pollution	4.29	3.27	High	4.29	4.29	High
RF16	Generation of Hazardous Waste	2.97	3.34	Medium	2.97	2.97	Medium
RF17	Unhealthy/Hazardous Work Environment	3.09	2.79	Medium	3.09	3.09	Medium
RF18	Human Rights Violations	2.28	2.43	Medium	2.28	2.28	Medium
RF19	Poor Fulfillment of Social Obligations	1.86	2.17	Low	1.86	1.86	Medium
RF20	Violation of Business Ethics	2.35	2.49	Medium	2.35	2.35	Medium

Based on the results, 10%, 70%, and 20% of risk factors of supply chains of the lead and zinc industry have low, medium, and high status, respectively, in terms of probability and impact.

4.6. Risk matrix (probability-detectability)

The status of each risk factor is presented in Figure 5.

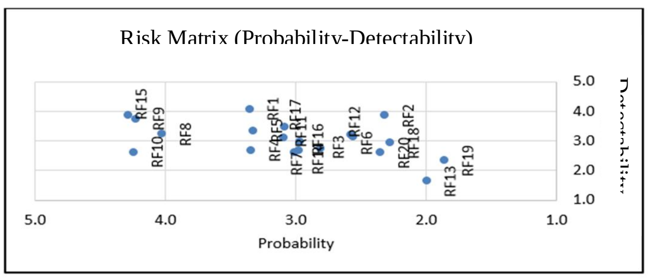

Fig. 5. Risk Matrix (Probability-Detectability)

In terms of probability and detectability, the risk factors that are highly probable and slightly detectable are considered high risks while those with low probability and high detectability are regarded as low risks. This is presented in Table 15.

The results indicate that, in terms of detectability and probability, 0%, 70%, and 30% of risk factors are at low, medium, and high levels, respectively. It is noteworthy that there is an overlap between the results of the probability-detectability matrix and the probability-impact matrix, as all high-risk factors in the latter are also among the high-risk factors in the former.

4.7.RPN-Based ranking of critical risks

In this stage, the Risk Priority Number (RPN) was employed to rank each of the risk factors affecting supply chain sustainability. To this end, the values of probability, impact, and detectability of risk factors were calculated based on the data obtained through the questionnaires and then, these three values were multiplied to obtain RPNs. The risk factors were then ranked based on calculated RPNs and the appropriate

strategies to reduce them were proposed. Table 16 present the RPN-based ranking of the 20 critical risk factors affecting supply chain sustainability in the lead and zinc industry.
Based on RPNs presented in Table 16, environmental pollution, price and cost fluctuations and lack of technological/knowledge sustainability, with RPNs of 58.29, 50.64, and 41.99, respectively, were identified as the most critical risk factors of SSCs in the lead and zinc industry.

4.8. Risk response strategy

Some specialized interviews were made with three experts of the lead and zinc industry to elicit their views and comments about risk response strategies (avoidance, exploitation, transfer/sharing, decrease/increase, and acceptance). The findings of these interviews are presented in Table 16. It should be noted that each of the interviewees was asked to propose at least two solutions for the reduction of each of the four critical risks (i.e. RF8, RF9, RF10, and RF15).

Tab. 15. RPN-Based ranking of critical risks

Ranking	Code of Risk Factor	Description of Risk Factor	RPN
1	RF15	Environmental Pollution	58.29
2	RF9	Price and Cost Fluctuations	50.64
3	RF8	Lack of Technological/Knowledge Sustainability	41.99
4	RF1	Uncertainty of Supply and Demand	37.54
5	RF16	Generation of Hazardous Waste	36.89
6	RF5	Poor Efficiency of Supply Process	34.49
7	RF17	Unhealthy/Hazardous Work Environment	33.76
8	RF10	Inflation and Exchange Rates	32.74
9	RF2	Failure to select the Right Supplier	27.58
10	RF11	Declining Market Share	24.21
11	RF14	Inefficient Utilization of Resources	23.95
12	RF6	Coordination Complexity	21.88
13	RF12	Brand/Reputation Weakening	21.76
14	RF4	Inflexibility of Supply Resources	21.55
15	RF3	Poor Accountability	21.39
16	RF7	Information Technology (IT) Risks	20.46
17	RF18	Human Rights Violations	19.31
18	RF20	Violation of Business Ethics	15.54
19	RF19	Poor Fulfillment of Social Obligations	13.45
20	RF13	Natural Disasters	10.78

Tab. 16. Critical risk response strategies

Risk Code	Risk Description	Response Strategy	Proposed Solutions
RF8	Lack of technological/knowledge sustainability	Avoidance/Reduction	1- Transferring knowledge from other countries 2- Developing R&D activities 3- Planning in-service training courses
RF9	Price and cost fluctuations	Avoidance/Reduction	1- Developing market planning and evaluation activities 2- Reducing capital turnover period 3- Developing control plans to reduce finished prices
RF10	Inflation and exchange rates	Avoidance/Reduction	1- Importing raw materials from other countries 2- Adopting export-oriented approaches
RF15	Environmental pollution	Avoidance/Reduction	1- Developing process knowledge 2- Developing recycling activities 3- Planning training courses on environmental issues

5. Discussion

This study aimed to investigate the risk factors of supply chain sustainability in the Iranian lead and zinc industry. To this end, the research questionnaire was filled out by eight experts of the industry, and the data were analyzed in descriptive and quantitative phases. In the descriptive phase, the demographics of the respondents were analyzed, and the mean, minimum, and maximum of the impact (temporal, financial, and functional), probability, and detectability were calculated. In the qualitative phase, the probability-impact matrix, the probability-detectability matrix, and RPNs were calculated. The obtained values were statistically analyzed to identify the top-priority risk factors and propose appropriate strategies for their reduction. The identification of the effective risk factors and proposal of appropriate strategies and solutions for reducing them can make it possible to maintain the efficiency of efficient units (periods) and improve the efficiency of inefficient units (periods) in terms of supply chain stability. Accordingly, the primary list of SSC risk factors was prepared based on the literature review and interviews with academic and industrial experts. A questionnaire was then distributed among the experts to finalize the list of risk factors. A total of 20 factors were identified as the critical risks of SSCs. The construct validity of these factors was confirmed based on the geometric mean given to each by experts, while their reliability was assessed using Cronbach's alpha. Based on the risk matrix (probability-impact), the findings indicated that 10%, 70%, and 20% of risk factors are at low, medium, and high levels, respectively. Moreover, 70%, of risk factors were at a medium level and 30% of them were at a high level, based on the probability-detectability matrix. RPNs also demonstrated that "environmental pollution," "price and cost fluctuations," and "lack of technological/knowledge sustainability" were the most critical risk factors of SSCs in the lead and zinc industry.

Considering the results obtained from the probability-impact and probability-detectability matrices and RPN-based ranking of the risk factors, it was observed that RF8, RF9, RF10, and RF15 were among the high risks not only in both matrices but also in RPN-based ranking. Some specialized interviews were conducted with three experts of the Iranian lead and zinc industry to determine appropriate risk response strategies for each of these four risk factors in order to maintain the efficiency of efficient periods and improve the efficiency of inefficient ones. Analysis of the risk factors affecting supply chain sustainability revealed that "lack of technological/knowledge sustainability," "price and cost fluctuations," "inflation and exchange rates" and "environmental pollution" were of a higher priority compared to other risk factors. Comparative results with the literature are presented in Table 17.

Tab. 17. Comparative results of risk factor analysis and the literature

Risk Factor	Literature
Lack of Technological/Knowledge Sustainability	[8, 17, 37, 44]
Price and Cost Fluctuations	[11, 20, 23, 44, 47]
Inflation and Exchange Rates	[18, 22, 29, 33, 41]
Environmental Pollution	[13, 20, 38, 43, 46]

6. Conclusions and Future Research

The objective of this study was to identify the most important risk factors affecting supply chain sustainability in the Iranian lead and zinc industry. To this end, in-depth interviews were made with 5 industrial and academic experts, and a questionnaire was distributed among 17 experts (including the five experts who participated in in-depth interviews). The findings indicated that one of the most critical risk factors of SSCs in the lead and zinc industry is "price and cost fluctuations." Considering the current conditions of the Iranian market and the low predictability of these variables, managers of this industry are recommended to "develop market planning and evaluation activities," "reduce the capital turnover period," and "develop controlling plans to reduce cost." In terms of "environmental pollution," as another critical risk factor, industry owners are recommended to take serious and continuous measures in order to "promote the knowledge of the process," "develop recycling activities" and "plan training courses on environmental issues." Other measures such as "establishment and maintenance of integrated management system (IMS)," "mulching of industrial waste depots" and "implementation of closed-cycle treatment of effluents and surface runoff" can have productive performance results. Finally, it should be noted that a major limitation of this study was the difficulty to access managers for interviews and completing the questionnaires due to their hectic work schedules. For future studies, it is suggested that sustainable supply chain risk assessment in the lead and zinc industry be done using machine learning and deep learning. In the present study, the evaluation of sustainability and identification of risk factors in the lead and zinc industry is considered, which can be developed for other industries, especially the electricity industry.

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