Supply Chain Risk Mitigation Based on The Integration of House of Risk and MOORA

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ABSTRACT

Supply chains play a critical role in the operational success of organizations, impacting both costs and product quality. However, they are often exposed to various risks that can disrupt business processes. This research aims to identify supply chain risks and propose mitigation strategies using the House of Risk (HOR) and Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) methods. Through interviews, key issues were identified in a fiberglass company's supply chain, including raw material supply fluctuations, procurement cost variability, defective materials, inappropriate specifications, outdated technology, insufficient worker skills, and ambitious company targets. The novelty of this study lies in the application of MOORA, which introduces a correlation matrix for risk mitigation by considering both cost minimization and benefit maximization. The analysis identified 12 risk agents and 26 risk events, which were prioritized using HOR stage 2 with the MOORA method. The top preventive actions were ranked, providing actionable recommendations for companies to address supply chain risks more effectively. The findings of this research offer practical insights for companies in the fiberglass industry to enhance supply chain resilience by integrating cost and benefit considerations into their risk management strategies.

1. Introduction

The supply chain is a critical component of a company's business operations, representing the flow of goods from upstream suppliers to downstream consumers. However, it is susceptible to various challenges that can disrupt this flow. Common issues include the Bullwhip Effect (BE), product variations, product aging, shifting customer demands, owner fragmentation, and the complexities brought about by globalization. The Bullwhip Effect, for instance, refers to the phenomenon where order variability intensifies as it moves upstream in the supply chain [1], [2]. Effective supply chain management ensures smooth business operations by controlling costs and product quality [3].

Companies must manage their supply chain as an integrated whole to avoid inefficiencies such as shortages or excesses in supply. Proper coordination across each link

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in the supply chain is vital to preventing disruptions that could negatively affect business processes and lead to financial losses [4]. Managing supply chain risks is also critical in ensuring long-term success, especially for firms engaged in international operations [5]. A lack of systematic risk management can significantly reduce a company's performance and overall resilience [6]. Supply chain risk management involves identifying, assessing, and mitigating risks that affect economic, social, and environmental factors, ensuring the sustainability of supply chain operations [7]. As emphasized by [8], effective risk management has a direct and significant impact on the success of a company's overall operations.

Previous research on the House of Risk (HOR) method has primarily focused on ranking preventive actions based on comparisons between risk agents and mitigation strategies. Studies conducted by [9-11] highlight this approach but also reveal limitations in expanding the criteria used for correlation matrix comparisons. Specifically, the criteria selected by experts are restricted within the existing framework of the HOR model, which does not allow for adding new variables or criteria [12]. This limitation is significant, especially in cases where a decision support system is required to assess both cost minimization and benefit maximization in risk mitigation [6], [11-18]. Thus, previous research has not fully addressed the complexity of integrating these factors into the HOR methodology, leaving gaps in the comprehensive evaluation of supply chain risks and their mitigation.

A limitation of previous research on supply chain risk mitigation is its reliance on Multi-Criteria Decision-Making (MCDM) systems without fully incorporating the critical factors of costs and benefits. In reality, companies consistently consider both costs and profits in their decision-making processes. It creates a gap in existing research, as many studies have not adequately addressed the need for a comprehensive approach that balances these factors. The novelty of this research lies in its focus on the decision-making process at the final stage of risk mitigation, emphasizing the integration of cost minimization and profit maximization principles. This research aims to map the risks across the supply chain and identify prioritized mitigation actions using a cost-benefit analysis framework. The Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) method was selected for this purpose, as it is well-suited for evaluating risk mitigation by considering company-specific criteria based on benefits and costs. MOORA, developed by Brauers and Zavadskas in 2006 [19-21], compares the alternatives' responses to a denominator that represents all objectives. This ratio system provides a structured approach to decision-making in complex environments [22].

The primary method employed in this study is the House of Risk (HOR), which is recognized as an effective strategy for identifying and addressing hazards along the supply chain of the Fiberglass Company. The HOR model is based on established methodologies such as Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD), as introduced by Geraldin, et al. [23] and Pujawan and Mahendrawathi [24]. The HOR framework is divided into two phases: risk identification and risk treatment [25]. It begins by mapping supply chain activities, identifying risks, and processing the matrix of risk agents and events to determine the priority of risks. Preventive actions are then developed to address these risks, resulting in a prioritized sequence of risk mitigation actions [26]. Integrating the MOORA method with the House of Risk framework provides a novel decision support system for risk mitigation. This approach identifies risks and prioritizes mitigation actions based on a cost-benefit analysis, making it a valuable tool for supply chain management. MOORA has been successfully applied in various decision-making problems in real-time manufacturing environments, demonstrating its practicality [27], [28]. This approach aligns with the company's principle that costs should

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be minimized while maximizing profits. The final step involves collaboration with policymakers to select appropriate mitigation strategies that suit the company's operational needs [15].

2. Methods

Produces various Fiberglass Reinforced Plastic (FRP) products and offers customized designs based on customer requests. Initial interviews revealed several significant issues within the company's supply chain processes, including production procedures that fail to meet expectations, worker fatigue due to overtime demands, and delays in raw material deliveries. These challenges, compounded by the company's high production targets, directly impact both efficiency and effectiveness, threatening long-term sustainability [6]. In several cases, production delays were caused by late delivery of crucial raw materials, such as fiber and matt, which extended production timelines. Other problems stem from production planning failures, leading to excess or inadequate inventory, which increases warehouse storage costs. Additionally, insufficient worker training has resulted in quality control failures, causing product rejections. Fluctuations in raw material prices have exacerbated the company's struggle to meet production targets.

Previous studies have identified similar risks in supply chain processes, including limited supply, rework, partner dependencies, raw material shortages, delayed shipments, stockouts, returns, bullwhip effect, and IT system failures [29], [30]. This study integrates multiple approaches to address these challenges, expanding comparison criteria to support decision-making. The Supply Chain Operations Reference (SCOR) model is applied to map supply chain activities. The data is processed through the House of Risk (HOR) methodology in stages 1 and 2, leading to the identification of priority preventive measures. These measures are then reanalyzed using the MOORA method, incorporating cost and benefit criteria to ensure alignment with the company's strategic goals. This novel approach, which has not been previously explored, offers a fresh perspective on implementing preventive actions within supply chain risk management. The detailed procedure of this research is illustrated in Figure 1.

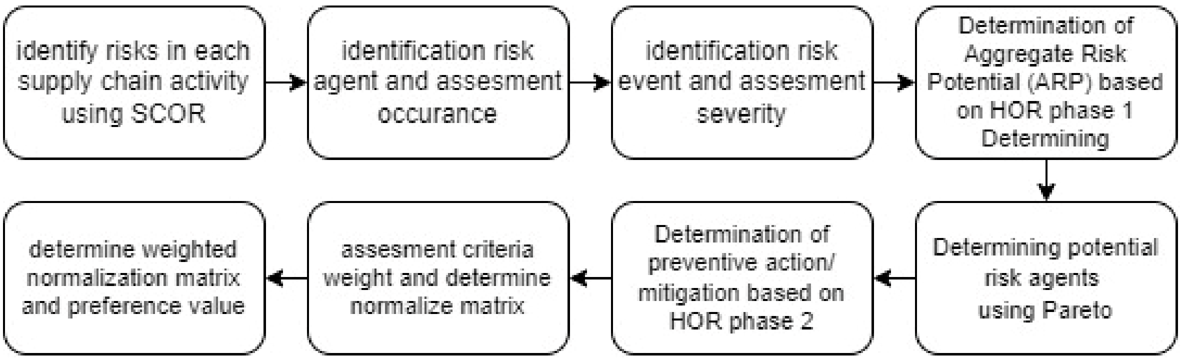

Figure 1. Research Procedures

2.1 Identify risk-based Supply Chain Operation Reference (SCOR)

The initial step in this research involves mapping the supply chain processes using the Supply Chain Operations Reference (SCOR) model. SCOR is a framework developed by the Supply Chain Council in 1996 to standardize the management of supply chain processes and enhance customer satisfaction [31]. The model categorizes supply chain

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activities into six primary processes: plan, source, make, deliver, return, and enable. Each of these processes encompasses various levels within the supply chain and includes management practices widely recognized across different industries (see Figure 2).

The mapping of supply chain activities is designed to identify each process and delineate the scope of the supply chain. Based on discussions with experts from Fiberglass Company, the supply chain processes were mapped as shown in Table 1.

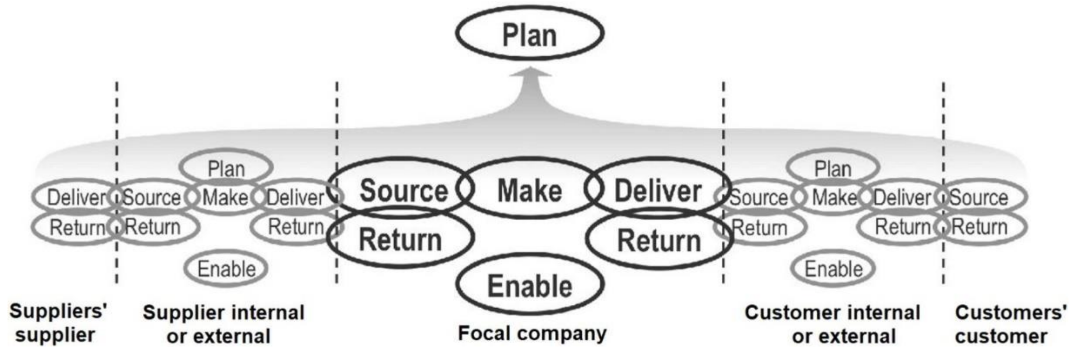

Figure 2. Major management processes proposed by the SCOR model

Table 1. Supply Chain Operation Reference

No	Process	Activity
1	Plan	1. Production planning and analysis
		2. Planning the procurement of materials and tools
2	Source	1. Procurement of materials and tools
		2. Raw material inspection
		3. Raw material storage
3	Make	1. Preparing raw materials for production
		2. Carry out the manufacturing process.
		3. Finishing production results
		4. Product storage in the Warehouse area
4	Delivery	1. Product Distribution
5	Return	1. Product returns that are not appropriate

Table 1 illustrates the supply chain activities defined by SCOR based on the input from company experts. Following the mapping process, the identification of risk events and risk agents was carried out (see Table 2). Each process and activity has specific risks that can disrupt supply chain operations. This detailed table illustrates the risk events and corresponding agents identified in the supply chain. These insights form the foundation for the risk management strategies applied in this study.

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Table 2. Results of Supply Chain Risk Event and Risk Agent Identification

Process	Activity	Code	Risk Event	Code	Risk Agent
Plan	Production planning and analysis	E1	Excess product inventory	A1	Uncertainty in the number of consumer orders
		E2	Lack of product inventory		
		E3	Changes to the production schedule	A2	Consumer demand adjustments
		E4	Product storage issue (limited storage space)		
	Planning the procurement of materials and tools	E5	Raw materials are in short supply	A3	Error in raw material calculation
		E5	Excess raw material inventory		
		E6	Changes in procurement costs	A4	Price fluctuations in raw materials
Source	Procurement of materials and tools	E7	A lack of materials impeded the manufacturing process.	A5	Delay in raw material delivery
		E8	The production target was not achieved.		
	Raw material inspection	E10	There is a defect in the raw material that was delivered.	A6	Unprofessional vendor
		E9	The specifications of the raw materials sent do not match.		
	Raw material storage	E11	Stacking of raw materials	A7	Warehouse management is not systematic
Make	Preparing raw materials for production	E12	Mistakes in prepared materials	A8	Human error
	Product color, catalyst, and resin material mixing	E13	Because the combination hardens faster, it cannot be manufactured.	A9	Weather conditions are unfavorable.
		E14	The mixture overflows	A8	Human error
		E15	Mixture not according to measurements		
	Matt fiber is placed in the mold	E16	Compilation requires time.	A9	Small matt fiber fragments
	Basting the mixture onto the mold's matt fiber	E17	Lapisan tidak merata	A8	Human error
	Wooden frame installation on mold	E18	Asymmetrical design	A10	The frame is made of wood
	Separation between the mold and the finished product	E19	Broken Products	A8	Human error
		E20	Defective product with holes	A9	Insufficient equipment
	Finishing production results	E21	Reject product	A8	Human error
	Product storage in the Warehouse area	E22	Products with physical defects (scuffed)	A8	Human error
Delivery	Product Distribution	E23	Excess product inventory	A11	The transportation fleet is limited
Return	Product returns that are not appropriate	E24	Lack of product inventory	A12	The product specs are incompatible
		E25	Changes to the production schedule		
		E4	Product storage issue (limited storage space)		

2.2 House of Risk

The House of Risk (HOR) model focuses on preventive measures aimed at minimizing the occurrence of risk agents by systematically identifying risk events. A single risk agent can be responsible for multiple risk events, and the HOR model assigns probabilities to these risk agents while assessing the severity of each risk event [9].

In the initial stages, a thorough examination of each activity within the business process was conducted to map existing issues [32]. The next stage involved identifying specific risk events and evaluating their severity. Experts with deep knowledge of their respective fields carried out this risk identification, and the company validated these findings [9]. The severity of risk events was then rated on a scale from 1 (no impact) to 10 (hazardous impact). Following this, risk agents were identified for each activity, and their occurrence probability was assessed on a scale from 1 (rare) to 10 (particular).

Stage 4 of HOR involves determining the Aggregate Risk Potential (ARP) based on phase 1. At this point, experts assessed the correlation between risk events and their respective agents. The ARP value was calculated as in Equation (1).

$$ARP_j = 0_j \sum_i S_j + R_{ij} \quad (1)$$

In stage 5, the most critical risk agents were identified using Pareto analysis [12]. In stage 7, preventive actions or mitigation strategies were determined through discussions with experts. These actions were designed to reduce the likelihood and severity of risk agents. The effectiveness of the preventive measures was reassessed based on the new values of risk agent severity and occurrence, which can be seen in Equation (2). The effectiveness-to-difficulty ratio (ETD) of implementing each preventive action was then calculated to prioritize mitigation efforts (Equation (3)).

$$TE_k = \sum_j ARP_j + E_{ij} \quad (2)$$

$$ETD_k = TE_k + D_k \quad (3)$$

Expert respondents who understood the company's operations provided input by rating the severity and occurrence of each risk event, as shown in
Table 3.

The severity and occurrence scores are determined through interviews and brainstorming sessions with expert respondents. These values serve as the basis for calculating the ARP and determining which risk agents should be prioritized for mitigation.

2.3 multi-objective optimization on the basis of ratio analysis (MOORA)

The MOORA method is widely used for multi-attribute optimization in decision-making processes [20], [33], and was first introduced by [34]. In this research, MOORA is applied to prioritize mitigation actions based on expert-determined criteria, with a focus on balancing benefits and costs. This method provides a structured framework for evaluating multiple alternatives and identifying the most effective course of action.

The first step in the MOORA process is constructing a decision matrix that represents the performance of various alternatives with respect to different criteria. The matrix is defined as Equation (4).

$$X = \begin{bmatrix} X_{i1} & \dots & X_{1n} \\ \dots & \dots & \dots \\ X_{m1} & \dots & X_{mn} \end{bmatrix} \quad (4)$$

Where X_{ij} is the performance measure of i^{th} alternative on j^{th} criterion, m is the number of alternatives and n is the number of criteria. Next, the decision matrix is normalized using Equation (5). Where r_{ij} represents the normalized value for each alternative on the given criterion.

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$$r_{ij} = \frac{x_{ij}}{\sum_{n=1}^{m} x_{ij}} \quad (5)$$

Table 3. Weighting of Severity and Occurrence

Code	Risk Agent	O	Code	Risk Event	S
A1	Uncertainty in the number of consumer orders	8	E1	Excess product inventory	7
A2	Consumer demand adjustments	5	E2	Lack of product inventory	8
A3	Error in raw material calculation	5	E3	Changes to the production schedule	9
A4	Price fluctuations in raw materials	7	E4	Product storage issue (limited storage space)	8
A5	Delay in raw material delivery	5	E5	Raw materials are in short supply	7
A6	Unprofessional vendor	7	E6	Excess raw material inventory	7
A7	Warehouse management is not systematic	9	E7	Changes in procurement costs	8
A8	Human error	9	E8	A lack of materials impeded the manufacturing process.	7
A9	Small matt fiber fragments	4	E9	The production target was not achieved	9
A10	The frame is made of wood	9	E10	There is a defect in the raw material that was delivered.	4
A11	The transportation fleet is limited	9	E11	The specifications of the raw materials sent do not match	9
A12	The product specs are incompatible	5	E12	Stacking of raw materials	7
			E13	Mistakes in prepared materials	3
			E14	Because the combination hardens faster, it cannot be manufactured.	8
			E15	The mixture overflows	8
			E16	Mixture not according to measurements	8
			E17	Compilation requires time.	7
			E18	Lapisan tidak merata	7
			E19	Asymmetrical design	9
			E20	Broken Products	9
			E21	Defective product with holes	9
			E22	Reject product	9
			E23	Products with physical defects (scuffed)	7
			E24	Delays in delivery	5
			E25	Consumers' product returns	9
			E26	Distribution costs increase	8

Once the decision matrix is normalized, weights are assigned to each criterion based on expert preferences, and these weights are applied to the normalized matrix. This step allows the model to reflect the relative importance of different criteria in decision-making.

The assessment value for each alternative is then calculated by finding the difference between the sum of beneficial criteria (those to be maximized) and the sum of non-beneficial criteria (those to be minimized), as shown in Equation (6). Where g is the number of criteria to be maximized, $(n - g)$ is the number of criteria to be minimized.

$$Asessment\ Value = \sum_{j=i}^{g} x_{ij}^{*} - \sum_{j=g+1}^{g} x_{ij}^{*} \quad (6)$$

Finally, the assessment values are ranked in descending order, with the highest value representing the most favorable alternative. This ranking provides the priority order of mitigation actions based on a ratio analysis of benefits and costs. Using MOORA

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ensures that the selected mitigation strategies align with operational objectives and financial constraints.

3. Results and Discussion

3.1 House of Risk Stage 1

The Aggregate Risk Potential (ARP) is calculated to prioritize the risk agents in the supply chain. The ARP is determined by assessing the severity and occurrence of each risk event and its corresponding risk agent. Once the ARP values are calculated, the risk agents are ranked from the highest to the lowest ARP values, as shown in Table 4.

Table 4. House of Risk Stage 1 presents the correlation between risk events (Ei) and the associated risk agents (Ai). For instance, risk agent A8, related to human error, has the highest ARP value of 6966, making it the top priority for mitigation. Other high-priority agents include A3 (errors in raw material calculation) and A6 (unprofessional vendors), with ARP values of 2970 and 2898, respectively. These results highlight the critical areas that require immediate attention to minimize disruptions in the supply chain.

Table 4. House of Risk Stage 1

Risk Event (Ei)	Risk Agents (Ai)												Severity of Risk Event (Si)
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	
E1	9		9	9									7
E2	9		9	9	9	9							8
E3	9		9		9	3							9
E4	3	9	3				9						8
E5	9	3	9	9	9	9							7
E6	1	3	9	9									7
E7	1	3	9										8
E8	1		9			9							7
E9			3		9	3							9
E10						9							4
E11						9							9
E12	3		3				9						7
E13								9					3
E14								9	9				8
E15								9					8
E16								9					8
E17								9					7
E18								9					7
E19								9		9			9
E20								9					9
E21								9					9
E22								9		9			9
E23													7
E24			9		9	9					9		5
E25								9				9	9
E26												9	8
Occurrence of Agent	8	5	5	7	5	7	9	9	4	9	9	5	
Aggregate Risk Potential	2768	690	2970	1827	1710	2898	1215	6966	288	1458	405	765	
Priority Rank of Agent	4	10	2	5	6	3	8	1	12	7	11	9	

A Pareto analysis was conducted to refine risk agent prioritization further, as illustrated in Figure 3. The Pareto diagram, commonly called the 80:20 rule, helps distinguish between critical and non-critical risk agents. It suggests that 80% of the company's losses are likely caused by 20% of the most significant risks. The company can mitigate most of the risk impact by focusing on high-priority risk agents, such as A8 (human error) [12]. This analysis allows for targeted preventive actions to be implemented, ensuring that resources are allocated effectively to address the most pressing risks in the supply chain.

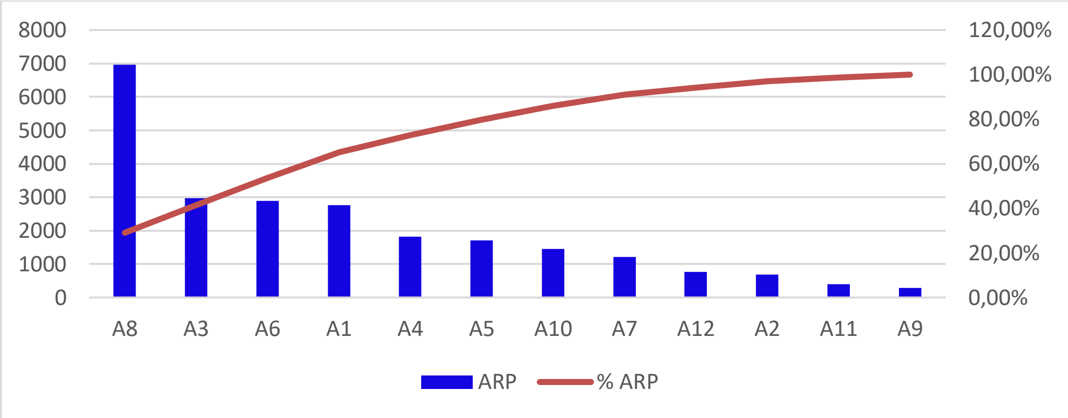

Figure 3. Agent Risk Pareto Diagram

3.2 Preventive Action

Following the first stage of the House of Risk analysis, specific mitigation strategies were developed, which are referred to as preventive actions. These actions address the prioritized risk agents identified in the previous stage. Table 5 outlines the preventive actions, their associated risk agents, and the degree of difficulty in implementing each action.

Table 5. Preventive Action

Code	Risk Agent	PAi	Preventive Action	Degree of Difficulty
A8	Human Error	PA1	Upgrading Skills	2
		PA2	Implement work-hour division.	3
		PA3	Increase the amount of employees	4
		PA4	Provide rewards for work achievements without errors	3
A3	Error in raw material calculation	PA5	Create a good procurement calculating system to reduce errors	4
		PA6	Creating effective standard operational processes	2
		PA7	Examine every raw material calculation	2
A6	Unprofessional vendor	PA8	Add another vendor's reserves that meet the criteria	2
A1	Uncertainty in the number of consumer orders	PA9	Improve the order administration system between producers and consumers.	3
A4	Price fluctuations in raw materials	PA10	Determine the selling price based on the price variations of raw materials.	4
A5	Delay in raw material delivery	PA11	Improve the inventory system so that there is no shortage of raw materials	3

After determining the appropriate mitigation measures and evaluating their difficulty, the next step involves analyzing the relationship between these preventive actions and the identified risk agents in House of Risk Stage 2.

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3.3 House of Risk Stage 2

In the second stage of the House of Risk analysis, preventive actions were evaluated based on their effectiveness in mitigating risks and the difficulty of implementing them. Table 6 shows the results of this evaluation, where the Aggregate Risk Potential (ARP) values are mapped against various preventive actions (PA) associated with each risk agent (Ai). The total effectiveness of each action is calculated and compared to the degree of difficulty in implementing the action, resulting in an Effectiveness to Difficulty Ratio (ETD).

Table 6. House of Risk Stage 2

Risk Event (Ei)	Risk Agents (Ai)											ARP
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	PA11	
A8	9	9	9	9	3	3			3			6966
A3					9	9	9					2970
A6								9				2898
A1									9			2768
A4										9		1827
A5											9	1710
Total effectiveness of action	62694	62694	62694	62694	47628	47628	26730	26082	45810	16443	15390	
Degree of difficulty performing action	2	2	4	3	4	2	2	2	3	4	3	
Effectiveness to difficulty ratio	31347	31347	15673,5	20898	11907	23814	13365	13041	15270	4111	5130	

Table 7 presents the ranking of the preventive actions based on their ETD values. The top-ranked actions include upgrading skills (PA1), creating effective standard operational processes (PA6), and implementing work-hour division (PA2). These actions are prioritized for implementation due to their high impact and feasibility. Other actions, such as improving the order administration system (PA9) and adding vendor reserves (PA8), also rank highly but have slightly lower ETD values. The prioritized list of preventive actions provides a clear roadmap for the company to focus on the most impactful and practical strategies for mitigating supply chain risks. This structured approach ensures that resources are allocated effectively, addressing the most critical risks while considering the ease of implementation.

Table 7. Preventive Action Rank

Code	Preventive Action	ETD	Rank
PA1	Upgrading Skills	31347	1
PA6	Creating effective standard operational processes	23814	2
PA2	Implement work-hour division.	20898	3
PA4	Provide rewards for work achievements without errors	20898	4
PA3	Increase the amount of employees	15673	5
PA9	Improve the order administration system between producers and consumers.	15270	6
PA7	Examine every raw material calculation	13365	7
PA8	Add another vendor's reserves that meet the criteria	13041	8
PA5	Create a good procurement calculating system to reduce errors	11907	9
PA11	Improve the inventory system so that there is no shortage of raw materials	5130	10
PA10	Determine the selling price based on the price variations of raw materials.	4110	11

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3.4 MOORA

A descriptive analysis was conducted to define the weights for each criterion, as shown in Table 8. The criteria include ease of implementation, impact on operational procedures, enhancement of productivity, reduction of risks, and improvement of the company's work culture. The weights were assigned based on expert opinions, with the highest priority given to actions that significantly reduce risks (35%), followed by actions that enhance productivity (20%) and are easy to implement (20%).

Table 8. Risk Mitigation Action Criteria

Criteria	Weight
Actions easy to implement	20 %
Actions do not disrupt operational procedures	15 %
Actions have an impact on enhancing productivity	20 %
Risks can be reduced by action	35%
Actions can help to improve the company's work culture	10%

The assigned weights for each sub-criterion, displayed in Table 9, were based on a range value from 1 to 4, depending on the experts' assessment of how each action fits within the specified criteria.

Table 9. Criteria Weight

Criteria	Range Value	Weight Value
Actions easy to implement	0 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4
Actions do not disrupt operational procedures	0 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4
Actions have an impact on enhancing productivity	0 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4
Risks can be reduced by action	0 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4
Actions can help to improve the company's work culture	0 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4

Table 10 presents the normalized decision matrix, which evaluates the performance of each alternative (preventive action) across multiple criteria. The matrix provides a comprehensive comparison, allowing each preventive action to be measured relative to the others in terms of both benefits and costs.

The normalized matrix weights are calculated to account for these factors, as seen in Table 10. Normalize Matrix

No	Alternative	Criteria Code				
		C1	C2	C3	C4	C5
1	Upgrading Skills	0,3746	0,1811	0,3780	0,2739	0,3612
2	Creating effective standard operational processes	0,1873	0,2716	0,1890	0,2739	0,2408
3	Implement work-hour division.	0,3746	0,3621	0,2835	0,2739	0,3612
4	Provide rewards for work achievements without errors	0,3746	0,3621	0,3780	0,3651	0,3612
5	Increase the number of employees	0,1873	0,2716	0,2835	0,2739	0,2408
6	Improve the order administration system between producers and consumers.	0,3746	0,3621	0,1890	0,2739	0,2408
7	Examine every raw material calculation	0,2810	0,2716	0,3780	0,3651	0,2408
8	Add another vendor's reserves that meet the criteria	0,1873	0,2716	0,2835	0,2739	0,2408
9	Create a good procurement calculating system to reduce errors	0,1873	0,3621	0,2835	0,3651	0,3612
10	Improve the inventory system so that there is no shortage of raw materials	0,2810	0,2716	0,1890	0,2739	0,2408
11	Determine the selling price based on the price variations of raw materials.	0,3746	0,2716	0,3780	0,2739	0,3612
Optimum		Min	Max	Max	Max	Max

Table 11. These weights reflect the relative importance of each criterion about the preventive actions. For instance, upgrading skills (PA1) and providing rewards for error-free performance (PA4) rank highly across multiple criteria, showcasing their broad effectiveness.

Table 10. Normalize Matrix

No	Alternative	Criteria Code				
		C1	C2	C3	C4	C5
1	Upgrading Skills	0,3746	0,1811	0,3780	0,2739	0,3612
2	Creating effective standard operational processes	0,1873	0,2716	0,1890	0,2739	0,2408
3	Implement work-hour division.	0,3746	0,3621	0,2835	0,2739	0,3612
4	Provide rewards for work achievements without errors	0,3746	0,3621	0,3780	0,3651	0,3612
5	Increase the number of employees	0,1873	0,2716	0,2835	0,2739	0,2408
6	Improve the order administration system between producers and consumers.	0,3746	0,3621	0,1890	0,2739	0,2408
7	Examine every raw material calculation	0,2810	0,2716	0,3780	0,3651	0,2408
8	Add another vendor's reserves that meet the criteria	0,1873	0,2716	0,2835	0,2739	0,2408
9	Create a good procurement calculating system to reduce errors	0,1873	0,3621	0,2835	0,3651	0,3612
10	Improve the inventory system so that there is no shortage of raw materials	0,2810	0,2716	0,1890	0,2739	0,2408
11	Determine the selling price based on the price variations of raw materials.	0,3746	0,2716	0,3780	0,2739	0,3612
Optimum		Min	Max	Max	Max	Max

Table 11. Weighted Normalization Matrix

No	Alternative	Criteria Code				
		C1	C2	C3	C4	C5
1	Upgrading Skills	0,0749	0,0272	0,0756	0,0959	0,0361
2	Creating effective standard operational processes	0,0375	0,0407	0,0378	0,0959	0,0241
3	Implement work-hour division.	0,0749	0,0543	0,0567	0,0959	0,0361

No	Alternative	Criteria Code				
		C1	C2	C3	C4	C5
4	Provide rewards for work achievements without errors	0,0749	0,0543	0,0756	0,1278	0,0361
5	Increase the amount of employees	0,0375	0,0407	0,0567	0,0959	0,0241
6	Improve the order administration system between producers and consumers.	0,0749	0,0543	0,0378	0,0959	0,0241
7	Examine every raw material calculation	0,0562	0,0407	0,0756	0,1278	0,0241
8	Add another vendor's reserves that meet the criteria	0,0375	0,0407	0,0567	0,0959	0,0241
9	Create a good procurement calculating system to reduce errors	0,0375	0,0543	0,0567	0,1278	0,0361
10	Improve the inventory system so that there is no shortage of raw materials	0,0562	0,0407	0,0378	0,0959	0,0241
11	Determine the selling price based on the price variations of raw materials.	0,0749	0,0407	0,0756	0,0959	0,0361
Optimum		Min	Max	Max	Max	Max

Finally, Table 12 shows the preference values for each alternative, computed by subtracting the minimum value (cost) from the maximum value (benefit). This step allows for a final ranking of preventive actions, prioritizing the most beneficial and cost-effective solutions. According to this analysis, the top-ranked actions include creating a good procurement system (PA5), providing rewards for work achievements (PA4), and examining every raw material calculation (PA7). These actions stand out due to their ability to deliver substantial benefits while maintaining manageable implementation costs. This ranking system offers a clear roadmap for selecting the most effective risk mitigation strategies, ensuring that decisions are financially sound and operationally efficient.

Table 12. Preferences Value

No	Alternative	Min	Max	Yi = Max-Min	Rank
		Cost	Benefit		
1	Upgrading Skills	0,0749	0,0272	0,0756	9
2	Creating effective standard operational processes	0,0375	0,0407	0,0378	8
3	Implement work-hour division.	0,0749	0,0543	0,0567	7
4	Provide rewards for work achievements without errors	0,0749	0,0543	0,0756	2
5	Increase the number of employees	0,0375	0,0407	0,0567	4
6	Improve the order administration system between producers and consumers.	0,0749	0,0543	0,0378	11
7	Examine every raw material calculation	0,0562	0,0407	0,0756	3
8	Add another vendor's reserves that meet the criteria	0,0375	0,0407	0,0567	4
9	Create a good procurement calculating system to reduce errors	0,0375	0,0543	0,0567	1
10	Improve the inventory system so that there is no shortage of raw materials	0,0562	0,0407	0,0378	10
11	Determine the selling price based on the price variations of raw materials.	0,0749	0,0407	0,0756	6

3.5 The implications of this research

The findings of this research provide significant implications for companies, particularly in developing a comprehensive risk management and mitigation model that integrates benefits and costs. This model allows companies to strategically select and implement risk mitigation actions that align with their financial and operational goals. Unlike previous approaches that prioritized mitigation actions based on limited criteria, the model introduced in this study incorporates a more robust analysis of cost-benefit trade-offs, as demonstrated in Table 12. This enhanced framework allows for more informed decision-making, enabling companies to address the most pressing risks in their supply chains while optimizing resource allocation.

The recommendations from this research are based on expert insights into the evolving risks within the Fiberglass supply chain. As a result, the proposed solutions are tailored to the specific needs and characteristics of the company. By adopting these recommendations, businesses can achieve more effective risk mitigation, ensuring smoother operations and greater resilience in supply chain disruptions.

4. Conclusion

This research has successfully identified and mapped the risks present in the supply chain using the SCOR model, which resulted in identifying 12 risk agents and 26 risk events. Through applying the House of Risk (HOR) methodology in Stage 1, six critical risk agents were prioritized for mitigation, leading to the development of 11 preventive actions. In Stage 2 of HOR, these risk agents were correlated with the preventive actions, resulting in the prioritization of mitigation measures. The highest-ranked actions included upgrading skills (PA1), creating effective standard operational processes (PA6), and implementing work-hour division (PA2). The Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) method further refined these priorities by incorporating a cost-benefit analysis. The final mitigation action rankings emphasized creating a good procurement calculation system (PA5) and rewarding work achievements (PA4).

However, one limitation of this study is the use of interval values for assessing the severity and occurrence of risks. These intervals can lead to variations in respondent perceptions, which may affect the consistency of the results. Future research should focus on adopting more precise, definite values for these parameters to ensure uniformity in risk assessments. For future studies, it is recommended to explore integrating other decision-making tools that could complement the HOR and MOORA methods. Additionally, further research could expand the scope by examining how external factors, such as market dynamics or regulatory changes, influence the effectiveness of risk mitigation strategies in supply chains.

Data Availability

This publication does not include all of the raw data. Please contact the author through email if you want the raw data.

Declarations

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