Risk Mitigation Strategy for Pallet-Feet Products at the Manufacturing Company

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ABSTRACT

Supply chain reliability is a crucial element in ensuring the smooth running of production processes, particularly for pallet-feet products at manufacturing company. The company faces several challenges, such as dependency on a single supplier, mismatches in raw material delivery schedules, substandard material quality, and fluctuating demand, all of which create uncertainty and operational risks. Moreover, the absence of a structured risk management system increases the potential for disruptions within the supply chain. This study aims to identify and mitigate key risks in the pallet-feet supply chain by integrating the House of Risk (HOR) and Analytical Hierarchy Process (AHP) methods. Data were collected through interviews and surveys with internal company stakeholders. The HOR method was used to identify and prioritize risks based on the Aggregate Risk Potential (ARP) value, while the AHP method was employed to determine the priority of mitigation strategies based on criteria of effectiveness, cost, and ease of implementation. The results of this study identified eigth priority risks and proposed 11 mitigation strategies, with the main strategy being the implementation of a double-checking system using sensors in the initial raw material inspection process due to its high effectiveness, optimal cost, and ease of application.

Keywords: aggregate risk potential, house of risk, pallet feet, risk mitigation, risk management, supply chain

A. Introduction

In the modern era, companies face various challenges in managing operational risks (Sihombing et al., 2024). One crucial area that requires special attention is the supply chain, as it encompasses the entire process from raw material procurement to finished product distribution (Ahmad et al., 2020). Risks arising in the supply chain can disrupt smooth operations, so it is necessary to implement an effective risk management system (Marimin & Muzakki, 2021).

Success in consistently maintaining a smooth supply chain is an important indicator of a company's operational performance (Nasution et al., 2024). However, in reality, this process is often not monitored or does not even run as expected in the field (Anisa et al., 2025). Each activity in the supply chain has different potential risks (Ginianti & Rukmi, 2022), so more structured risk management is needed, one of which is through the implementation of supply chain management.

E ISSN 2442-3149 | P ISSN 2355-472X
https://journal.itltrisakti.ac.id/index.php/jmtranslog

Supply Chain Management (SCM) manages the flow of materials, information, and finances from suppliers to consumers efficiently, covering various activities such as procurement, production, storage, and after-sales service (Nabila et al., 2022). Kusnadi (2024) states that the main goal of SCM is to create added value through cost reduction, quality improvement, and rapid response to market demand. However, according to Wistin & Alamsjah (2024), the complexity that arises from the involvement of various parties such as suppliers, producers, distributors, and consumers often gives rise to potential disruptions and operational risks.

Risks in SCM can come from supply delays, demand fluctuations, production failures, quality issues, price instability, regulatory changes, and external disruptions such as natural disasters or global crises (Deviyanti et al., 2022), all of which can disrupt the smooth operation and stability of the business (Sitanggang et al., 2024). Therefore, risk management analysis in SCM is a crucial activity to anticipate uncertainties that occur, maintain supply chain stability, and ensure the integration and sustainability of material and information flows.

Risk management is a process carried out systematically to identify, evaluate, and control risks that can disrupt the smooth running of business operations (Santana et al., 2023). In the supply chain, risk management aims to prevent disruptions in the availability of raw materials, production, and delivery of products to consumers. According to Wijaya et al. (2022), this process includes identifying risk sources, assessing impacts, and developing mitigation strategies. Miradji et al. (2024) explain that with good supply chain risk management, companies can reduce losses and maintain smooth business processes.

Supply Chain Risk Management (SCRM) is an integration between risk management and SCM, which aims to manage risks from upstream to downstream of the supply chain (Nafi'ah & Mahbubah, 2021). This approach not only includes assessing internal risks, such as production delays or raw material quality, but also takes into account external factors such as economic conditions, regulatory changes, or natural disasters that can impact supply chain flows (Cong et al., 2024). To support effective SCRM implementation, one approach that can be used is the House of Risk.

House of Risk (HOR) is a risk management method developed to systematically analyze and identify sources of risk in a supply chain (Hadi et al., 2020). This method focuses on mapping the relationship between potential risks (risk events) and their causal factors (risk agents), as well as determining the priority of mitigation actions based on the Aggregate Risk Potential (ARP) value (Ardiansyah & Nugroho, 2022). HOR consists of two phases, namely the risk identification and assessment phase and the risk mitigation strategy development and prioritization phase. Meanwhile, to further facilitate the decision-making process in determining mitigation strategies, the Analytical Hierarchy Process can be used in determining mitigation strategy decision-making.

Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method developed by Thomas L. Saaty. AHP is used to determine the priority of alternatives based on certain criteria through pairwise comparisons (Wulandari & Bulan, 2019). In the context of supply chain risk management, AHP can assist in selecting the most effective risk mitigation strategies by considering factors such as cost, effectiveness, and ease of implementation (Puji & Yul, 2021). By combining HOR and AHP, risk analysis can be carried out in a more structured manner to produce optimal recommendations.

In line with the importance of risk management, Supply Chain Risk Management (SCRM) is becoming an increasingly relevant topic (Aljabhan, 2023). Many studies highlight the need for risk identification and mitigation in order to improve operational performance. One of the studies in the same field is by Zulfikar & Mustofa (2022) at PT Charoen

Pokphand Indonesia Tbk., which uses the HOR method and is motivated by fluctuations in demand for broiler chicks and the absence of systematic risk analysis in the company.

However, there is still a research gap in the integration between HOR and AHP or the Supply Chain Operation Reference (SCOR) approach, which has not been widely explored. One of them is the research conducted by Asrory (2023) and Liddin & Pulansari (2024), which shows that although they have used SCOR and HOR for risk identification and mitigation recommendations, neither has used AHP for mapping and determining mitigation priorities in a structured manner.

In addition, existing research often does not consider industry or company-specific contexts, as is done by Liddin & Pulansari (2024) so that the recommendations produced are not entirely relevant to the situation faced by a particular company, such as PT X. This gap shows that the integration of HOR and AHP methods to map and prioritize risk mitigation strategies in SCM is still limited and rarely found in previous studies. This further emphasizes that risk management in the field of supply chain management is a very important and strategic aspect for the sustainability of company operations, especially amidst the dynamics and uncertainty of the current global market.

This study has a novelty in the form of a comprehensive integration of the House of Risk (HOR) and Analytical Hierarchy Process (AHP) methods in the context of the pallet foot component manufacturing industry. Although the HOR method has been widely used for risk identification and mapping and AHP for multi-criteria decision-making, the combination of the two in the specific context of the pallet foot product supply chain in manufacturing companies has not been widely found in previous studies. This approach allows for more systematic risk identification and determination of more structured and weighted mitigation strategies based on relevant criteria.

The lack of research that integrates the HOR and AHP methods in the context of a specific industry and the lack of formal risk management implementation at PT X are strong reasons for conducting this study. In addition, demand fluctuations and field findings related to delays and quality of raw materials further emphasize the urgency of a systematic risk assessment. This study is expected to provide practical contributions for PT X in improving operational efficiency and smoothness and strengthening the company's competitiveness amidst market uncertainty.

Therefore, considering the importance of risk management in the supply chain and the lack of research that comprehensively integrates the HOR and AHP methods, this study seeks to fill this gap. Moreover, PT X, as a manufacturing company for machine components and pallet feet, also faces problems of complexity and risk in its supply chain. Thus, it is necessary to identify and formulate risk mitigation strategies to improve the smoothness and efficiency of its operations.

Based on the background above, it can be identified that in PT X there are various problems in the supply chain of pallet feet products that require special attention. One of the main issues is uncertainty at every stage of the supply chain, from raw material procurement to product distribution. This uncertainty has the potential to disrupt the smooth flow of materials and slow down the production process, thereby reducing the company's ability to meet customer demand.

PT X is a manufacturing company engaged in the provision of machine components, dollies, pallet feet, and other engineering services. The complexity of the company's supply chain is mainly due to the fulfillment of raw materials, high production targets, and dependence on various suppliers, which creates various risks in daily operations. One of the company's main products, namely pallet feet, was chosen as the focus of the study because it has fluctuating but consistent demand characteristics throughout the year, greatly affecting the smoothness of production.

E ISSN 2442-3149 | P ISSN 2355-472X
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The demand data for pallet feet over the past year, from January 2023 to June 2024, shows considerable fluctuation. There were significant increases, such as in March 2023, and sharp declines, particularly in February 2024. This trend indicates that any disruption in the supply chain, such as delays in raw material delivery or supplier-related issues, could hinder the production process and cause the company to miss market opportunities due to delayed order fulfillment.



Figure 1 Pallet Feet Product

In addition, delays in raw material shipments and the receipt of materials that do not meet quality standards have occurred frequently. These problems increase the risk of production delays and may negatively impact product quality and delivery speed. Such conditions could reduce customer satisfaction and weaken the company's competitiveness in the future.

Field observations also revealed that PT X has never conducted a formal risk analysis of its supply chain. In fact, based on the 2018 Supplier Quality Management System audit, PT X has been certified with ISO, which requires a systematic risk management plan. Failure to comply with this requirement could affect the company's credibility in the eyes of customers and external auditors.

Given these conditions, it is essential to conduct a study that identifies the sources of risk and formulates appropriate mitigation strategies to anticipate uncertainty and disruption in the supply chain. This research applies an integrated method using the House of Risk and Analytical Hierarchy Process to systematically identify priority risk sources and determine the most effective mitigation strategies.

B. Methods

This research uses a quantitative descriptive approach with a case study of the pallet feet supply chain at PT X. Primary data was obtained through structured interviews and questionnaires with three internal company experts directly involved in the supply chain process. Secondary data was collected from

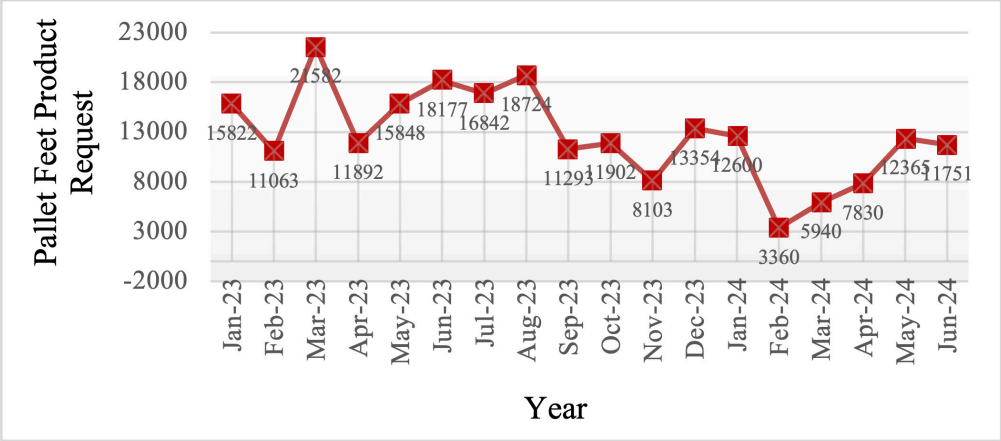

Figure 2 Pallet Feet Demand Data for the Last 1 Year

company documents, production records, shipping reports, and supporting literature related to supply chain risk management. The sampling technique used purposive sampling, with respondents based on predetermined criteria. The ideal number of experts ranges from three to seven, allowing for a more structured and scientifically acceptable decision-making process. Several key factors considered in expert selection were their positions.

Data collection was conducted in two stages: first, risk identification and assessment using the House of Risk (HOR) instrument, phase 1 and phase 2, to obtain Aggregate Risk Potential (ARP) values and risk agent priorities; second, mitigation strategy prioritization using the Analytical Hierarchy Process (AHP) method based on three criteria: effectiveness, cost, and ease of implementation.

Data analysis was conducted in a structured manner. HOR is used to map the relationship between risk events and risk agents and determine the priority of risk agents requiring immediate mitigation action. Next, AHP is used to select the optimal mitigation strategy by pairwise comparing alternatives against predetermined criteria.

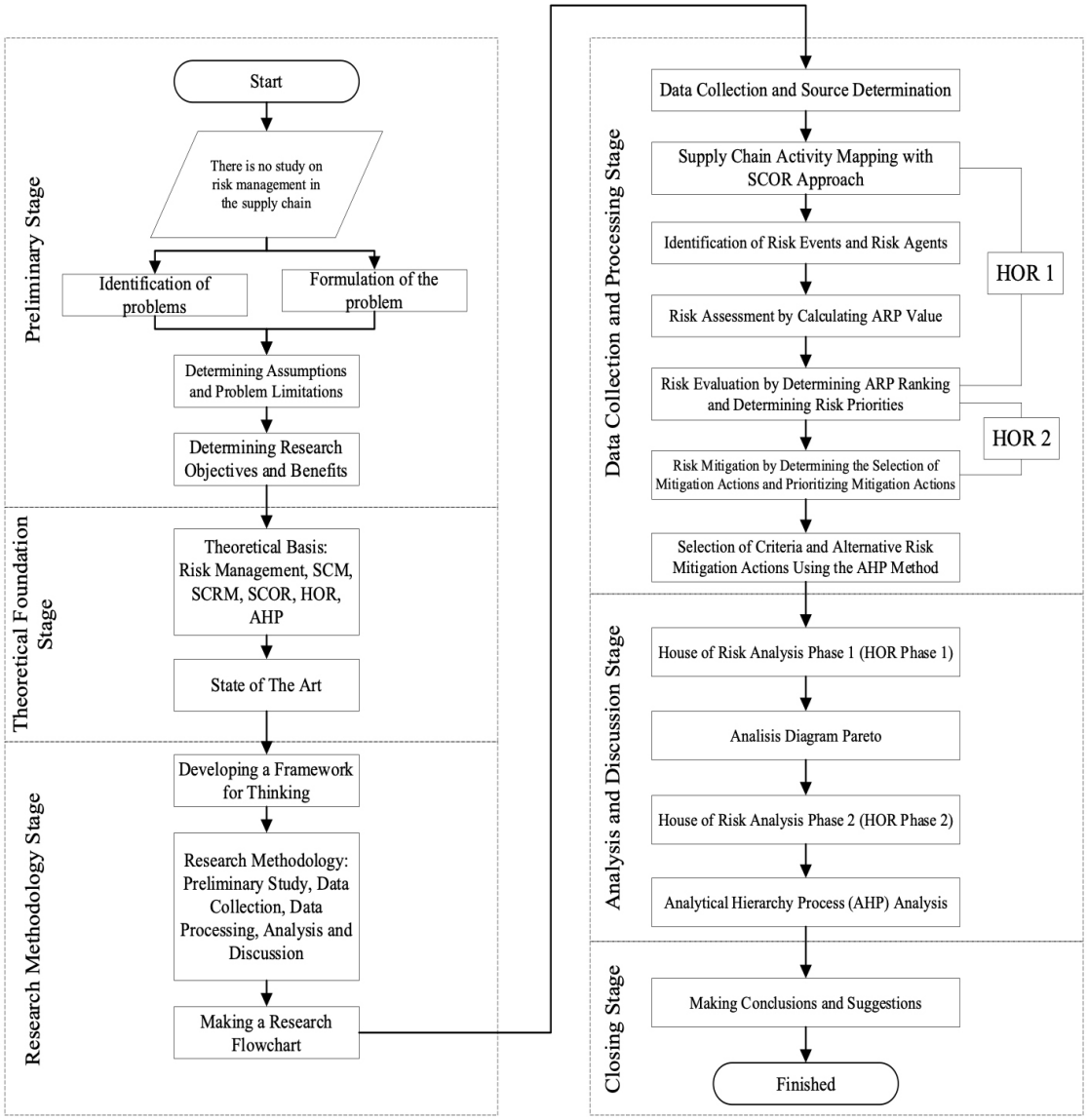

Figure 3 Research Flow

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Table 1 Risk Identification in Supply Chain Activities

Process	Activity	Risk Events	Risk Agents
Plan	Pallet Feet Material Procurement Planning	Errors in material requirements planning lead to shortages or excess stock.	a. Miscalculations in raw material requirements planning. b. Mismatch between production capacity and stock targets.
	Pallet Feet Production Process Planning	Unpredictable changes in market demand cause production imbalances.	a. Reliance on inaccurate demand data. b. The system's inability to adapt production forecasts to market trends.
Source	Pallet Feet Material Procurement	Delay in delivery of raw materials from suppliers	a. Suppliers do not have sufficient production capacity b. Logistical disruptions (weather, traffic jams, fleet limitations) c. Lack of alternative suppliers
		The instability of raw material prices affects production costs.	a. Fluctuations in raw material prices due to economic or regulatory factors. b. Lack of long-term contracts with stable suppliers.
	Pallet Feet Material Inspection	Pallet Feet material does not meet specifications	a. Suboptimal supplier quality control. b. Errors in initial raw material inspection. c. Insufficiently stringent material acceptance procedures.
Make	Pallet Feet Production Process	5.1 Machine or production equipment failures that cause production delays.	a. Lack of maintenance and care of production machines. b. Limited availability of spare parts.
	Pallet Feet Product Quality Inspection	5.2 Production results are defective or do not meet quality standards.	a. Ineffective quality control system. b. Unskilled or poorly trained production operators. c. Operator negligence (human error)
Delivery	Delivery of Finished Products to Customers	5.3 Delay in delivery of finished products to customers	a. Delayed product readiness due to production problems.
Return	Return of Defective Raw Materials to Supplier	Delay in raw materials replaced by supplier	a. Expedition Error
	Return of Defective Finished Products from Customers	The desired product does not match the customer's request	a. Errors in pre-shipment quality inspection b. Substandard product handling during transportation c. Product specifications do not meet customer requirements

AHP calculations are performed using Expert Choice software to ensure assessment consistency (Consistency Ratio < 0.1). The complete research flow is depicted in Figure 3.

C. Results and Discussion

This section presents the results of the analysis and further discusses their implications in relation to the research objectives. The findings are elaborated systematically, beginning with risk identification, followed by risk assessment, and concluding with the proposed mitigation strategies.

1. Risk Identification

The first step in identifying risks is to hold discussions with experts to identify the various risks that may arise in the supply chain business process. Identification is carried out by thoroughly understanding the company's business process flow. The results of the risk identification process in the company's supply

Table 2 Severity Value of Risk Events

Code	Risk Events	Severity
E1	Errors in material requirements planning lead to shortages or excess stock	1
E2	Unpredictable changes in market demand cause production imbalances	2
E3	Delay in delivery of raw materials from suppliers	5
E4	The instability of raw material prices affects production costs.	9
E5	Pallet Feet material does not meet specifications	2
E6	Machine or production equipment failures that cause production delays.	2
E7	The production results are defective or do not meet quality standards.	3
E8	Delay in delivery of finished products to customers	1
E9	Delay in raw materials replaced by supplier	9
E10	The desired product does not match the customer's request	1

chain are shown in Table 1.

2. Risk Assessment

After identifying risk events and risk agents, the next step is to assess the level of impact (severity), frequency of occurrence (occurrence), and the relationship between the risk event and its cause (correlation). Risk assessments of severity and occurrence use a scale of 1–10 based on the Failure Mode and Effects Analysis (FMEA) method, which is considered effective in providing measurements and allows for more detailed assessments (McDermott et al., 2009), so that it can help in prioritizing risks more accurately. The scale refers to (McDermott et al., 2009). The following are the results of the severity assessment given by the expert based on the impact caused by each risk incident in the supply chain of Pallet Feet products at PT

Table 3 The value of the probability level of occurrence of a risk agents

Code	Risk Agents	Occurrence
A1	Miscalculation in raw material requirements planning.	1
A2	Mismatch between production capacity and stock targets.	1
A3	Reliance on less accurate demand data.	5
A4	The system's inability to adjust production forecasts to market trends.	4
A5	The supplier does not have sufficient production capacity.	2
A6	Logistical disruptions (weather, traffic jams, fleet limitations).	6
A7	Lack of alternative suppliers.	1
A8	Fluctuations in raw material prices due to economic or regulatory factors.	6
A9	Lack of long-term contracts with stable suppliers.	1
A10	Quality control from suppliers is not optimal.	5
A11	Errors in initial inspection of raw materials.	4
A12	Less stringent material acceptance procedures.	7
A13	Lack of maintenance and care of production machines.	2
A14	Limited spare parts.	6
A15	Ineffective quality control system.	2
A16	Production operators are less skilled or have minimal training.	2
A17	Operator Negligence (Human Error).	6
A18	Delayed product readiness due to production issues.	1
A19	Expedition Error.	1
A20	Errors in quality inspection before shipment.	2
A21	Product handling during transportation is not up to standard.	1
A22	Non-conformity of product specifications with customer needs.	1

E ISSN 2442-3149 | P ISSN 2355-472X
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Table 4 Risk House Model Phase 1

Risk Events	Risk Agents																					Severity of Risks
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	
E1	9	9	3	3													1						1
E2	3	1	9	3														1					2
E3	1	3	1	1	3	3	1	3		1	3	1		1	3				1	3		1	5
E4		3	1	3		1	1	9		1	1	3	9	1		1		3					9
E5			1	1	3	3	1	1		9	9	3	1	1	9	3	3			9	3	9	2
E6				1									9	3		3							2
E7		3									9	9	3	9	9	9	9	3		9	9	9	3
E8	9	9	3	3		1	1	3	1	3	9	3	1		1	1		3	3	1	1	9	1
E9	1		1		1	9	3	1	1	9	3	3			1		1		3	3	3		9
E10	1										3		1			9	9	1		3	1	9	1
Occ. of Agents	1	1	5	4	2	6	1	6	1	5	4	7	2	6	2	2	6	1	1	2	1	1	
ARP	39	71	245	192	60	672	44	660	10	580	432	623	224	294	140	114	312	42	35	182	62	68	
Rank	20	14	8	10	17	1	18	2	22	4	5	3	9	7	12	13	6	19	21	11	16	15	

X, as shown in Table 2.

The following are the results of the occurrence assessment that have been given by experts based on the frequency of occurrence of each risk in the supply chain of Pallet Feet products at PT X, as listed in Table 3.

3. Risk Evaluation

After obtaining the severity and occurrence assessment results for each risk event and risk agent (risk cause), the next step is to determine the correlation between the two. The correlation value scale is determined based on the assessment of the expert respondents, namely 0, 1, 3, and 9. Then simultaneously, the next stage in the House of Risk (HOR) phase 1 is to calculate the Aggregate Risk Potential (ARP) for each risk agent. This ARP calculation is carried out by considering the severity, occurrence, and correlation values so that it can be used to determine priorities in risk mitigation efforts. The ARP value is obtained using Equation 2-1, and the calculation results from the HOR phase 1 model can be seen in Table 4.

At this stage, risk agents are evaluated to determine which risk factors should be addressed first. Priority is determined by ranking their Aggregate Risk Potential (ARP) values from highest to lowest. Risk agents with the highest ARP values are considered the most critical risk factors and require immediate mitigation, while those with lower values are the next priority. The results of the risk agent ranking based on priority level can be seen in Table 5.

In the risk evaluation process at this stage, a Pareto diagram can be used to identify risk agents that have the most significant impact on the supply chain. The Pareto 80/20 principle states that 80% of risk events are generally caused by 20% of the primary risk factors. Using a Pareto diagram, risk factors can be prioritized, starting from the most crucial and requiring immediate action to those with lesser impact and can be addressed at a later stage.

Based on the 80/20 principle, 8 risk agents were obtained from a total of 22 risk agents who have a dominant influence in the supply chain of Pallet Feet products at PT X. The following Pareto diagram was compiled based on the results of the aggregate risk potential calculation in the House of Risk phase 1. The results of this analysis can be seen in Figure 4.

Table 5 Risk Agent Priority Ranking Based on ARP Value

Risk Agents Code	ARP	Cumulative ARP	% ARP	Cumulative % ARP
A6	672	672	13.17%	13.17%
A8	660	1332	12.94%	26.11%
A12	623	1955	12.21%	38.33%
A10	580	2535	11.37%	49.70%
A11	432	2967	8.47%	58.17%
A17	312	3279	6.12%	64.28%
A14	294	3573	5.76%	70.05%
A3	245	3818	4.80%	74.85%
A13	224	4042	4.39%	79.24%
A4	192	4234	3.76%	83.00%
A20	182	4416	3.57%	86.57%
A15	140	4556	2.74%	89.32%
A16	114	4670	2.23%	91.55%
A2	71	4741	1.39%	92.94%
A22	68	4809	1.33%	94.28%
A21	62	4871	1.22%	95.49%
A5	60	4931	1.18%	96.67%
A7	44	4975	0.86%	97.53%
A18	42	5017	0.82%	98.35%
A1	39	5056	0.76%	99.12%
A19	35	5091	0.69%	99.80%
A9	10	5101	0.20%	100.00%

Based on the application of the 80/20 Pareto diagram principle and discussions with experts, eight risk agents were prioritized for follow-up. The selection was based on their impact on the risk in the Pallet Feet supply chain at PT X. The identification results for

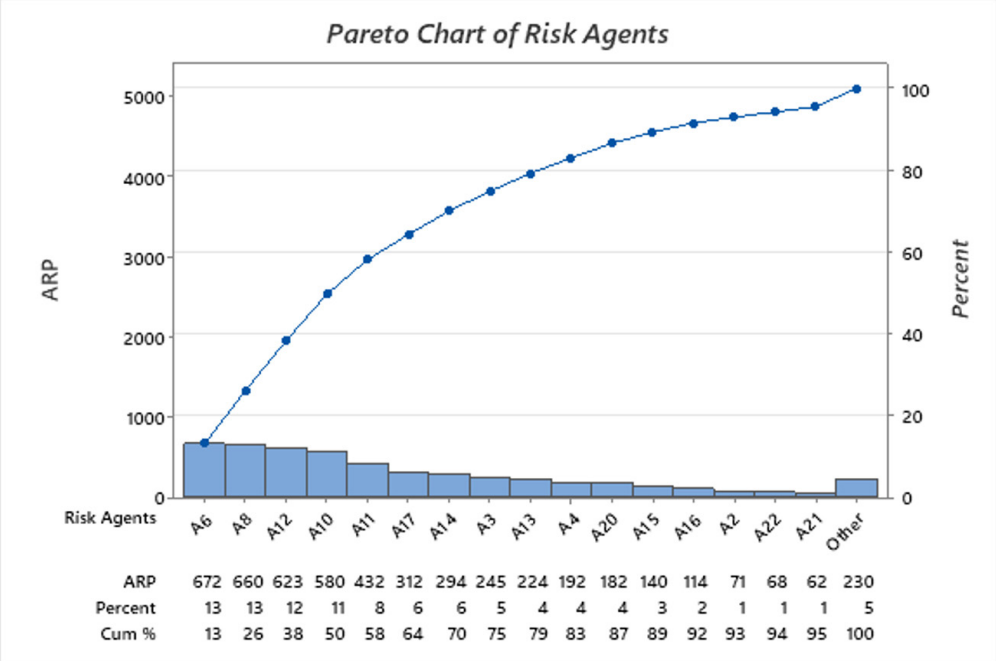

Figure 4 Pareto Diagram Results

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Table 6 Risk Agents Priority Order for Follow-Up

Rank	Risk Agents	Code
1	Logistical disruptions (weather, traffic jams, fleet limitations).	A6
2	Fluctuations in raw material prices due to economic or regulatory factors.	A8
3	Less stringent material acceptance procedures.	A12
4	Quality control from suppliers is not optimal.	A10
5	Errors in initial inspection of raw materials.	A11
6	Operator Negligence (Human Error).	A17
7	Limited spare parts.	A14
8	Reliance on less accurate demand data.	A3

these priority risk agents are shown in Table 6.

4. Mitigation Strategy Proposal Design

Based on the eight risk agents identified through the Pareto diagram, a series of preventive actions or proposed mitigation strategies are required to reduce or eliminate potential risks that may arise in the supply chain of pallet-feet

at PT X. These preventive actions were designed based on discussions with experts to ensure effective mitigation strategies that are appropriate to the company's conditions. The proposed steps also aim to minimize the possibility of risks occurring and increase the resilience of the supply chain system. The results of the recommended preventive actions that can be implemented at PT X are presented in Table 7.

5. Correlation Assessment of Management Strategies with Risk Agents

The correlation between mitigation strategies and risk sources in the Pallet-Feet supply chain at PT X was assessed using a four-point scale. This scale consists of a value of 0, indicating no relationship, and values of 1, 3, and 9, which represent weak, moderate, and strong correlation levels, respectively. The assessment was based on expert opinion to determine the extent to which each mitigation strategy can contribute to addressing the identified risk sources. The results of the

Table 7 Proposed Mitigation Strategy

No	Risk Agents	Preventive Action	Code
1	Logistics disruptions (weather, traffic jams, fleet limitations).	Arrange deliveries outside peak hours to avoid congestion.	PA1
		Provide reserve stock of raw materials & finished products to anticipate delivery delays.	PA2
2	Fluctuations in raw material prices due to economic or regulatory factors.	Enter into long-term contracts with suppliers to keep raw material prices stable with fixed price agreements.	PA3
3	Less stringent material acceptance procedures.	Provide training to the goods receiving team to conduct more detailed initial inspections.	PA4
		Implementing SOP for receiving materials by using a standard raw material checklist form	PA5
4	Quality control from suppliers is not optimal.	Create a vendor rating system to provide supplier performance scores.	PA6
5	Errors in initial inspection of raw materials.	Implementing the double-check system for initial inspection of raw materials	PA7
6	Operator Negligence (Human Error).	Provide training to operators periodically	PA8
		Implementing a poka-yoke system to prevent human error	PA9
7	Limited spare parts for production machines	Implementing a Predictive Maintenance System using historical data and IoT sensors to predict when machine parts need to be replaced before damage occurs.	PA10
8	Reliance on less accurate demand data.	Implementing better forecasting methods using digital systems	PA11

Table 8 Correlation Assessment between Mitigation Strategies and Risk Agents

Risk Agents	Preventive Action										
	PA1	**PA2**	**PA3**	**PA4**	**PA5**	**PA6**	**PA7**	**PA8**	**PA9**	**PA10**	**PA11**
A6	9	9	3			3					9
A8		3	3								3
A12				9	9	1	9	3	3		
A10	1	3	1	1	1	9	9	1	1		1
A11				9	9	3	9	3	3		
A17					1		1	9	9	1	
A14										9	1
A3		1	1								9

correlation evaluation between mitigation strategies and risk sources can be seen in Table 8.

6. Determining Degree of Difficulty

The degree of difficulty represents the degree to which a preventive measure is easy or difficult to implement. The assessment scale used consists of three levels: 3 for low difficulty, 4 for medium difficulty, and 5 for high difficulty. The determination of the difficulty level value is carried out based on interviews with experts from PT X. The results of the evaluation regarding the level of difficulty of each preventive measure can be seen in Table 9.

7. Calculation of Total Effectiveness and Effectiveness to Difficulty Ratio

The total effectiveness calculation is performed to assess the effectiveness of a preventive measure in reducing or eliminating risk. This evaluation is based on the relationship between the mitigation action and the identified risk sources. Meanwhile, the effectiveness-to-difficulty ratio is calculated as a comparison between the effectiveness of the preventive action and the degree of difficulty of its implementation. Through this calculation, a risk mitigation strategy can be determined that has an optimal impact with a level of difficulty that is still realistically applicable. The results of this calculation are presented in Table 10, which shows the House

Table 9 Determination of Degree of Difficulty

Code	Preventive Action	Dk
PA1	Arrange deliveries outside peak hours to avoid congestion.	3
PA2	Provide reserve stock of raw materials & finished products to anticipate delivery delays.	4
PA3	Enter into long-term contracts with suppliers to keep raw material prices stable with fixed price agreements.	3
PA4	Provide training to the goods receiving team to conduct more detailed initial inspections.	3
PA5	Implementing SOP for receiving materials by using a standard raw material checklist form.	3
PA6	Create a vendor rating system to provide supplier performance scores.	3
PA7	Implementing the Double Check System for initial inspection of raw materials.	3
PA8	Provide training to operators periodically.	3
PA9	Implementing a poka-yoke system to prevent human error.	4
PA10	Implementing a Predictive Maintenance System using historical data and IoT sensors to predict when machine parts need to be replaced before damage occurs.	5
PA11	Implementing better forecasting methods using digital systems	5

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Table 10 Risk House Model Phase 2

Risk Agents	Preventive Action											ARP
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	PA11	
A6	9	9	3			3					9	672
A8		3	3								3	660
A12				9	9	1	9	3	3			623
A10	1	3	1	1	1	9	9	1	1		1	580
A11				9	9	3	9	3	3			432
A17					1		1	9	9	1		312
A14										9	1	294
A3		1	1								9	245
TEk	6628	10013	4821	10075	10387	9155	15027	6553	6553	2958	11107	
Dk	3	4	3	3	3	3	3	3	4	5	5	
ETDk	2209	2503	1607	3358	3462	3052	5009	2184	1638	592	2221	
Rank	7	5	10	3	2	4	1	8	9	11	6	

of Risk model phase 2.

8. House of Risk Model Phase 2

The House of Risk model phase 2 was used to prioritize the most effective risk management measures to minimize the identified risk sources. Table 10 presents the results of the phase 2 analysis, indicating the mitigation strategies deemed to have the most significant impact on reducing potential risks.

Furthermore, based on the effectiveness-to-difficulty ratio value, a sequence of mitigation strategies can be determined that are highly effective with a level of implementation difficulty that is still feasible. The resulting sequence of mitigation strategy priorities is presented in Table 11.

Based on the calculations, the primary mitigation strategy chosen was to implement a double-check system for initial inspections. This measure aims to minimize the risk of errors in raw material receipt, ensure material quality before entering the production process, and improve inspection accuracy through more systematic double-checking.

9. Decision Hierarchy Construction

In this study, the AHP method is used to

Table 11 Mitigation Strategy Sequence

Rank	Code	Preventive Action
1	PA7	Implementing the Double Check System for initial inspection of raw materials.
2	PA5	Implementing SOP for receiving materials by using a standard raw material checklist form.
3	PA4	Provide training to the goods receiving team to conduct more detailed initial inspections.
4	PA6	Create a vendor rating system to provide supplier performance scores.
5	PA2	Provide reserve stock of raw materials & finished products to anticipate delivery delays.
6	PA11	Implementing better forecasting methods using digital systems.
7	PA1	Arrange deliveries outside peak hours to avoid congestion.
8	PA8	Provide training to operators periodically.
9	PA9	Implementing a poka-yoke system to prevent human error
10	PA3	Enter into long-term contracts with suppliers to keep raw material prices stable with fixed price agreements.
11	PA10	Implementing a Predictive Maintenance System using historical data and IoT sensors to predict when machine parts need to be replaced before damage occurs.

assist experts in determining alternative risk mitigation strategies that have been selected in the results of the House of Risk phase 2. Alternative mitigation strategies analyzed include the implementation of the Double Check System in the initial inspection of raw materials, which aims to reduce the impact of risks on the supply chain of pallet foot products at PT X. The determination of these alternatives is carried out to provide the best recommendations to experts in choosing the most effective initial steps in implementing risk mitigation strategies.

The results of the AHP method show the priority weight of each alternative mitigation strategy based on predetermined criteria so that the most optimal strategy can be obtained to be implemented in an effort to minimize risks in the company's supply chain. In the AHP method, the decision-making process begins by constructing a hierarchical structure that serves as a conceptual approach. The hierarchy is used to systematically organize problems, facilitating analysis of each element that influences decision-making.

This approach allows for more structured decision-making by considering various factors that influence the effectiveness of mitigation strategies in reducing risks in the pallet foot product supply chain at PT X. The three levels of hierarchy in the AHP method can be seen in Figure 5.

Based on Figure 5, the AHP hierarchical structure is used to determine the most optimal risk mitigation strategy in implementing the Double Check System. The AHP hierarchical structure consists of three levels: objectives, evaluation criteria, and alternative strategies. At Level 1, the main objective is to select the most effective Double Check System strategy in improving the reliability of production inspections. Level 2 includes three main criteria for assessing each alternative strategy (a) Costs, which reflect the amount of investment required to implement a particular strategy. (b) Effectiveness, which measures the extent to which the strategy is able to detect and prevent errors in the production process, and (c) Ease of implementation, which assesses the level of ease in adopting the strategy into an existing system.

Furthermore, at Level 3, there are four alternative strategies or models that are considered in implementing the Double Check System. The alternative strategies or models that have been compiled are based on the results of discussions with experts at PT X, so that they are relevant to the needs and conditions at PT X. The four alternatives are:

a. Manual Double Check by Different Inspectors

   The first model relies on manual

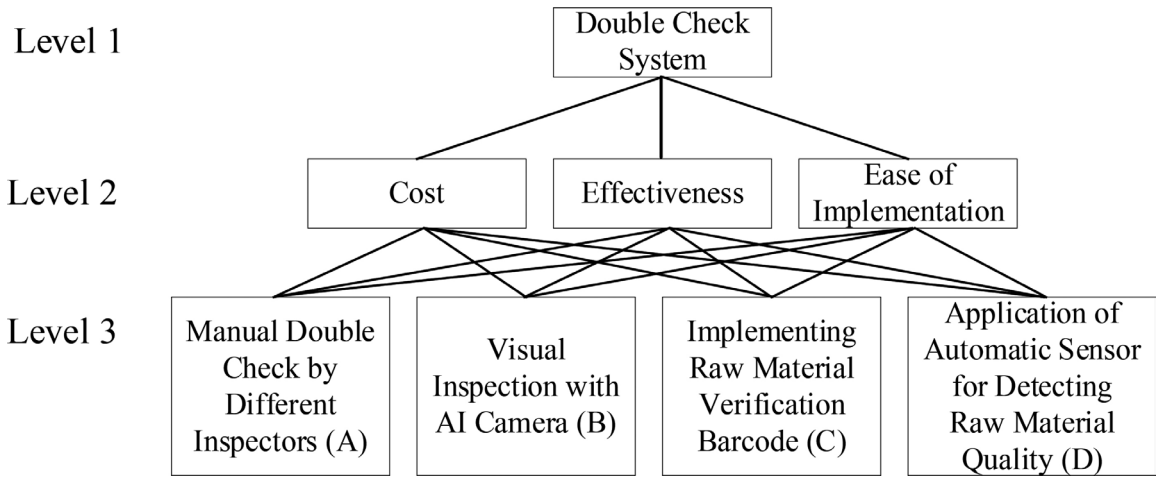

Figure 5 AHP Hierarchy of Risk Mitigation Alternatives

inspections by two different inspectors to ensure the accuracy of the results. Each inspector performs the inspections independently to minimize the possibility of human error.

b. Visual Inspection with Artificial Intelligence (AI) Camera

The second model utilizes high-resolution cameras equipped with artificial intelligence (AI) to automatically detect defects or non-conformities in raw materials and products, thereby increasing the consistency of inspection results.

c. Implementing Barcode or RFID for Raw Material Verification

In a third alternative model, each raw material is labeled with a barcode or RFID tag containing detailed information about the material. This model allows for more accurate tracking and minimizes the risk of misidentification of raw materials during the production process.

d. Application of Automatic Sensors for Raw Material Quality Detection

The fourth alternative is to use specialized sensors, such as color sensors, ultrasonic sensors, or optical sensors, to detect the physical characteristics of raw materials. This system, which is the fourth alternative, can automatically classify materials based on predetermined quality parameters.

Each alternative strategy is evaluated based on predetermined criteria using the AHP method. The results of this analysis are expected to provide recommendations for risk mitigation strategies that best suit the conditions at PT X.

10. AHP Processing Results

The AHP questionnaire was completed by senior managers acting as experts, comparing the importance of each criterion and assessing each alternative based on specific criteria. The expert's results were displayed in yellow boxes indicating the selected values. The weighted results were then processed using the AHP method, based on the theory developed by Saaty (2008). In this method, the weightings assigned by the experts are considered valid

Table 12 Weighting and Consistency Test between Criteria

Weighting and Consistency Test between Criteria

Criteria	Paired Comparison Test			Normalization			Total Weight Matriks	Eugen Vector	Matrix Multiplication	Eigen Value	λ Maks	CI	RI	CR	Result
	Cost	Effectiveness	Ease of Implementation	Cost	Effectiveness	Ease of Implementation									
Cost	1.000	3.000	7.000	0.677	0.714	0.538	1.930	0.643	2.010	3.124					
Effectiveness	0.333	1.000	5.000	0.226	0.238	0.385	0.849	0.283	0.867	3.065					
Ease of Implementation	0.143	0.200	1.000	0.097	0.048	0.077	0.221	0.074	0.223	3.023	3.071	0.034	0.580	0.059	Consistent
Total	1.476	4.200	13.000	1.000	1.000	1.000	3.000	1.000	3.100	9.212					

Table 13 Weighting and Consistency Test of Cost Criteria against Alternatives

Weighting and Cost Consistency Test for Alternatives

Cost	Paired Comparison Test				Normalization				Total Weight Matriks	Eugen Vector	Matrix Multiplication	Eigen Value	λ Maks	CI	RI	CR	Result
	A	B	C	D	A	B	C	D									
A	1.000	0.500	0.200	0.143	0.067	0.059	0.058	0.072	0.256	0.064	0.261	4.080					
B	2.000	1.000	0.250	0.333	0.133	0.118	0.072	0.169	0.492	0.123	0.494	4.014					
C	5.000	4.000	1.000	0.500	0.333	0.471	0.290	0.253	1.347	0.337	1.387	4.118	4.085	0.028	0.900	0.031	Consistent
D	7.000	3.000	2.000	1.000	0.467	0.353	0.580	0.506	1.905	0.476	1.966	4.128					
Total	15.000	8.500	3.450	1.976	1.000	1.000	1.000	1.000	4.000	1.000	4.108	16.340					

Table 14 Weighting and Consistency Test of Effectiveness Criteria against Alternatives

Weighting and Consistency Test of Effectiveness against Alternatives

Effectiveness	Paired Comparison Test				Normalization				Total Weight Matriks	Eugen Vector	Matrix Multiplication	Eigen Value	λ Maks	CI	RI	CR	Result
	A	B	C	D	A	B	C	D									
A	1.000	3.000	0.500	0.143	0.097	0.250	0.086	0.090	0.522	0.131	0.537	4.112					
B	0.333	1.000	0.333	0.200	0.032	0.083	0.057	0.126	0.298	0.075	0.303	4.060					
C	2.000	3.000	1.000	0.250	0.194	0.250	0.171	0.157	0.772	0.193	0.828	4.292	4.221	0.069	0.900	0.076	Consistent
D	7.000	5.000	4.000	1.000	0.677	0.417	0.686	0.628	2.408	0.602	2.661	4.420					
Total	10.333	12.000	5.833	1.593	1.000	1.000	1.000	1.000	4.000	1.000	4.328	16.884					

Table 15 Weighting and Consistency Test of Ease of Implementation Criteria for Alternatives

Weighting and Consistency Test of Ease of Implementation of Alternatives

Ease of Implementation	Paired Comparison Test				Normalization				Total Weight Matriks	Eugen Vector	Matrix Multiplication	Eigen Value	λ *Maks*	CI	RI	CR	Result
	A	B	C	D	A	B	C	D									
A	1.000	3.000	5.000	7.000	0.597	0.409	0.385	0.816	2.206	0.478	3.337	6.985					
B	0.333	1.000	3.000	0.333	0.199	0.136	0.231	0.169	0.735	0.159	0.652	4.098					
C	0.200	0.333	1.000	0.250	0.119	0.045	0.077	0.127	0.368	0.080	0.299	3.751	4.091	0.029	0.900	0.033	Consistent
D	0.143	3.000	4.000	1.000	0.085	0.409	0.308	0.506	1.308	0.283	1.148	4.052					
Total	1.676	7.333	13.000	8.583	1.000	1.000	1.000	1.617	4.617	1.000	5.437	18.886					

if the Consistency Ratio (CR) value does not exceed 0.1. The following presents the results of the weighting calculations and consistency tests based on the questionnaires completed by the experts in this study.

The weighting calculation begins by summing the values in each column in the comparison matrix. For example, in the cost criterion, the total column value is 1,000 + 0.333 + 0.143 = 1,476. A similar process is carried out for the effectiveness and ease of implementation criteria with totals of 4,200 and 13,000, respectively. Then, normalization is carried out by dividing each value in the column by the total of that column. For example, a value of 0.677 is obtained from 1,000 ÷ 1,476 and 0.226 from 0.333 ÷ 1,476. After normalization, the Total Weight Matrix is calculated by summing the values in each row, for example 1,930 for the cost criterion (0.677 + 0.714 + 0.538). The Eigen Vector value is obtained by dividing the total row by the number of criteria (3), so for cost it becomes 0.643 (1,930 ÷ 3). Next, matrix multiplication is performed to obtain new values: cost 2,010, effectiveness 0,867, and ease of implementation 0,223, for a total of 3,100. The Eigen Value is calculated by dividing the multiplication result by the Eigen Vector, resulting in 3,124, 3,065, and 3,023. The max λ value is 3,071, resulting in CI = 0,034 and CR = 0,059. Since CR < 0,1, the weighting is considered consistent. This process is also applied to Tables 13 to 15 for weighting and consistency testing between criteria and alternatives.

After calculating and processing the data for weighting and testing the consistency of the criteria for the alternatives, the next step is point 3, which is decision-making, namely determining the most appropriate type or model of the double-check system. The selection is based on the weight value of each alternative, with the alternative with the

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highest value prioritized for selection. This is in accordance with the AHP concept proposed by Saaty (2008), The alternative with the highest weight is considered the most optimal choice for improving the quality of raw material inspection to support the implementation of mitigation measures. The following table shows the selection of double-check system models based on the AWE value:

11. Decision-making

After weighting and consistency testing, the best double-check system alternative is determined using the Alternative Weight Evaluation (AWE) calculation. The AWE value is obtained by multiplying the criteria weights and eigenvalues of each alternative. The alternative with the highest AWE value is selected as the optimal option.

Based on Table 16, alternative D (Application of Automatic Sensors for Raw Material Quality Detection) has the highest AWE value, which is 0.498, followed by alternative C (Implementing Barcode or RFID for Raw Material Verification) with a value of 0.277. This shows that alternative D is the most optimal choice to be implemented in the double-check system because it has a higher weight compared to other alternatives. The AWE calculation process is carried out by adding the results of the multiplication of the criteria weights and the eigenvector values of each alternative. Mathematically, the calculation carried out is ((0.643×0.476) + (0.283×0.602) + (0.074×0.283)) = 0.498. These results indicate that alternative D has the greatest weight in supporting the double-check system, so it is chosen as the most appropriate or recommended model to be implemented by the company.

D. Conclusion

This study successfully identified 10 risk events and 22 risk drivers in the pallet-feet supply chain at PT X. Through a House of Risk analysis, eight priority risks were identified, with the highest Aggregate Risk Potential (ARP) value of 672, related to the risk of logistics disruption, and the lowest value of 245, related to reliance on inaccurate demand data. The integration of the House of Risk and Analytical Hierarchy Process methods resulted in 11 mitigation strategies. The primary recommended strategy is the implementation of a Double-Check System using detection sensors during the initial inspection of raw materials, as it was deemed the most effective, economical, and easy to implement. These findings demonstrate the academic contribution of integrating HOR and AHP in the context of the component manufacturing industry, particularly pallet feet, a field rarely explored in previous research.

Based on the limitations of this study, future studies are recommended to expand the scope of study to include products with

Table 16 Double-Check System Model Selection

	Eigen Vector				
Criteria	**Cost**	**Effectiveness**	**Ease of Implementation**	**Alternative Weight Evaluation**	**Rank**
Criteria Weight	0.643	0.283	0.074		
Alternative					
(Manual) A	0.064	0.131	0.478	0.113	3
(AI) B	0.123	0.075	0.159	0.112	4
(Barcode) C	0.337	0.193	0.080	0.277	2
(Sensor) D	0.476	0.602	0.283	0.498	1
		Total		1.000	

different supply chain characteristics to obtain more comprehensive generalizations of mitigation strategies. Furthermore, the method can be developed through the integration of Fuzzy AHP or other quantitative approaches to accommodate uncertainty in the decision-making process. The practical implication of this research is the availability of a systematic framework for companies to identify and prioritize supply chain risks and select optimal mitigation strategies. The theoretical implication is the strengthening of the supply chain risk management literature with an integrative approach of HOR and AHP. Thus, the novelty of this research lies in the combined application of the two methods, which can provide more measurable and applicable mitigation strategy recommendations to improve the reliability of manufacturing supply chains.

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