Kementerian Perindustrian REPUBLIK INDONESIA

Available *online* at : http://jurnal.poltekapp.ac.id/

Jurnal Manajemen Industri dan Logistik

| ISSN (Print) 2622-528X | ISSN (Online) 2598-5795 |

POLITEKNIK APP JAKARTA

article category: Logistic Management

Risk Mitigation Strategies for Creative Batik Manufacturing Supply Chains Using the House of Risk Method and Supply Chain Operations Reference

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ARTICLE INFORMATION

Article history:

Received: November 03, 2025
Revised: January, 15, 2026
Accepted: May 02, 2026

Keywords:

Batik Supply Chains
House of Risk
Risk Mitigation
Supply Chain Operations Reference
Supply Chain Risk Management

ABSTRACT

The batik supply chain faces several risks, including transportation errors, unpredictable weather, and human errors, which can disrupt operations, reduce efficiency, and weaken competitiveness. This study aims to identify risk events and risk agents in the batik supply chain, prioritize key risk sources, and propose mitigation strategies. The study integrates the Supply Chain Operations Reference (SCOR) and House of Risk (HOR). Priority risks include transportation mode errors, unpredictable weather, sudden order increases, human errors, and room temperature changes. Seven mitigation actions were proposed, including establishing expedition contracts, applying First-in-First-Out order prioritization, and providing regular worker training, prioritized by effectiveness-to-difficulty ratio, with the highest at 1984,5. This study contributes to supply chain risk management literature by applying the SCOR–HOR framework to traditional craft-based SMEs and highlighting the influence of worker skills, environmental uncertainty, and supplier dependency on supply chain risks.

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INTRODUCTION

Batik is an important part of Indonesia's cultural heritage. On October 2, 2009, UNESCO recognized Batik as an Intangible Cultural Heritage, and this date is now celebrated annually as National Batik Day. [1]. Batik is not only a cultural heritage but also an important contributor to Indonesia's economy, particularly in the textile industry. It supports the government's Making Indonesia 4.0 initiative to enhance national competitiveness in the global market. [2]. In fact, the batik industry is a big deal economically, contributing about 20% to Indonesia's GDP, 30% to tax revenue, and a whopping 74% to national exports [2]. As part of Indonesia's SMEs, the batik industry faces challenges such as dependence on external raw materials, demand fluctuations, transportation delays, production errors, and unsuitable storage conditions. These issues can disrupt supply chain operations, reduce efficiency, and weaken competitiveness.

Previous studies have examined supply chain risks across various industries. For example, Chopra and Sodhi identified supplier unreliability and transportation delays as major risks, while Tang highlighted the impact of weather and human error on traditional textile production [3][4]. On the other hand, Pujawan and Geraldin introduced the House of Risk (HOR) model a practical method for ranking and addressing risks in SMEs, though their study mainly focused on general manufacturing [5]. Kleindorfer and Saad created a framework for dealing with rare but devastating disruptions [6], while Jüttner *et al*. broke supply chain risks into three categories: operational, external, and network-related [7]. Wagner and Bode showed how vulnerabilities, like issues with transport or suppliers, can hurt performance [8]. Manuj and Mentzer dug into the cultural and logistical challenges of global supply chains for traditional products [9], Christopher and Peck stressed the need to plan for resilience [10].

Then there's Rao and Goldsby, who pinpointed environmental and process risks relevant to textile SMEs [11], and Sodhi *et al*., who noted that most risk management strategies aren't tailored to specific industries [12]. Blackhurst *et al.*, and Thun and Hoenig offered methods for manufacturing and automotive supply chains [13], [14], while Tummala and Schoenherr pushed for structured frameworks to tackle these problems [15]. Despite extensive research on supply chain risk management, few studies have specifically addressed the batik industry. Most studies focus on general manufacturing or textile industries and pay limited attention to the cultural and operational characteristics of batik production. Important issues such as dependence on external raw materials and environmental factors, including temperature changes, remain underexplored. In addition, integrated frameworks such as SCOR and HOR have rarely been applied in the batik industry, creating a gap in the literature.

Traditional risk management approaches tend to focus on mitigating immediate disruptions, such as inventory buffers or supplier diversification, without addressing the deeper uncertainties that drive risk [16]. Several scholars have highlighted that traditional risk management frameworks, while effective in large-scale manufacturing, often fail to capture the operational fragility of SMEs, where informal logistics arrangements, limited storage infrastructure, and labor dependency significantly amplify the impact of disruptions [17]. Empirical evidence suggests that transportation reliability, climate variability, and human operational error remain dominant risk drivers in craft-based and traditional manufacturing sectors [18].

Research studies over the past five years have increasingly emphasized supply chain resilience, particularly among SMEs facing high uncertainty and resource constraints [19]. The post-COVID-19 pandemic disruption has shifted academic attention toward adaptive risk mitigation strategies, digital monitoring tools, and flexible logistics partnerships as critical drivers of resilience in vulnerable supply chains [20], [21]. Mathematical and stochastic modeling techniques have also emerged as tools to minimize uncertainty and generate optimal supply chains [22]. This method allows managers to simulate various scenarios in developing supply chain strategies that perform well even under worst-case conditions [23]. However, many of these models are still largely theoretical, and there is an urgent need to bridge the gap between conceptual frameworks and real-world applications.

Several studies have also explored the application of Multicriteria Decision Making (MCDM) approaches to optimize supply chain risk management across various industries [24] [25]. Some studies have also used a digitalization-based approach using the House of Risk to enhance supply chain resilience [26]. Studies exploring HOR and SCOR tend to be conducted separately across various industry contexts, such as the food or manufacturing sectors, without placing them within a comprehensive framework for traditional SMEs in developing countries [27], [28]. Furthermore, current resilience-oriented models emphasize rapid recovery and flexibility [29], but rarely incorporate structured risk prioritization tools, such as the House of Risk (HOR), combined with process-based mapping frameworks such as SCOR. This gap indicates a lack of a risk mitigation framework grounded in analysis and tailored to traditional SMEs characterized by environmental sensitivity, manual production processes, and reliance on decentralized suppliers. Therefore, this study fills this literature gap by presenting an integrated framework model combining SCOR as the basis for process mapping and HOR as a measurable risk prioritization tool applied to batik SMEs in Indonesia The integration of the SCOR framework with the HOR method in the context of creative batik manufacturing offers a novel contribution that systematically identifies dominant risk sources and formulates feasible mitigation strategies that align with the operational realities of SMEs facing supply chain disruptions in the post-pandemic era. There are several important problems with the studies. First, in terms of parameters, previous studies frequently focus on board risk categories without directly linking risk events to quantifiable risk agents and their interrelations within the supply chain framework. Second, regarding the methodological approach, most studies use SCOR, FMEA, or MCDM in isolation, rather than integrating process mapping and risk prioritization into a cohesive analytical framework. Third, in terms of empirical context, most studies focus on contemporary or semi-digitalized industries, neglecting traditional SMEs characterized by manual production systems, environmental sensitivity, and decentralized supplier networks. Consequently, these methodologies are insufficient to fully encapsulate the intricacies and particularities of risk propagation within the conventional batik supply chain.

In recent study, E. Yuliawati and I.K. Tjahjani [30], examine how Kampoeng Batik Jetis manages supply chain risks amid business uncertainty such as the Covid-19 pandemic. The study employs FMEA and HOR Phase 2 as methods, with SCOR 12.0 used to model the supply chain processes, covering plan, source, make, deliver, return, and enable processes. The results indicate that the sustainability of the handwritten batik industry in Kampoeng Batik Jetis depends on resilient supply chain processes that can withstand disruptions and demand uncertainty. Mitigation actions are designed to address risks from suppliers, batik artisans, and workplace conditions, especially during the COVID-19 pandemic.

A study by E. Laela [31], addresses risk management in traditional batik SMEs, where production and management practices remain largely conventional, and formal risk management systems have not yet been adopted. Risk identification was conducted through interviews to determine risk events, their impacts, risk agents, risk occurrence, and the relationships between risk events and risk agents, using the ISO 31000 framework. This is followed by deeper analysis with the HOR model. Eight mitigation strategies were proposed, including worker motivation briefings, a clear reward and punishment system, customer relationship management implementation, recruitment of IT capable administrative and marketing staff, establishment of service standards, employee training, and improved social media management. The study does not incorporate a structured supply chain process framework, such as SCOR, which limits the ability to identify risks throughout end-to-end supply chain activities.

Similarly, a study by M. Ulfah [32], focused on mitigating supply chain risks in Batik Krakatoa by applying SCOR-based process mapping combined with FMEA, QFD, and the HOR approach. Risks were identified and evaluated to determine priority risk agents, and the HOR phase 2 generated 10 key mitigation actions related to workforce training, coordination, equipment updates, and production planning. The research emphasizes continuous improvement to strengthen supply chain resilience against operational disruptions.

This study aims to mitigate these limitations by executing a thorough analysis of the creative batik manufacturing supply chain utilizing an integrated SCOR-HOR framework. The study aims to (1) systematically delineate supply chain processes, (2) identify and quantify risk events and risk agents, (3) prioritize critical risk sources according to their cumulative impact, and (4) formulate targeted and actionable mitigation strategies. This method helps batik SMEs better understand supply chain risks in a structured and context-sensitive way, which will help them become more resilient and stay competitive after the pandemic.

SCOR provides a structured framework for process-based supply chain management and helps organizations improve supply chain effectiveness. In creative batik manufacturing, SCOR terminology supports the mapping of supply chain activities, from raw material procurement and production processes to product delivery. This process mapping helps identify supply chain activities and potential risks within the batik manufacturing supply chain. This study combines qualitative and quantitative approaches using the SCOR and House of Risk (HOR) frameworks. Data were collected through field observations, interviews, brainstorming sessions with batik SMEs and stakeholders, and supporting production data. In HOR Phase 1, risks are prioritized using Aggregate Risk Potential (ARP), while HOR Phase 2 ranks mitigation strategies based on the Effectiveness-to-Difficulty (ETDk) ratio to ensure practical and feasible solutions. This integrated SCOR-HOR approach provides a structured method for identifying and mitigating supply chain risks in batik SMEs, while supporting operational resilience and the sustainability of the batik industry as a cultural and economic asset. [5].

Research Design

This study uses a mixed-methods approach to analyze qualitative and quantitative aspects of the batik supply chain. Data were collected through field observations, semi-structured interviews, and brainstorming sessions. Quantitatively, HOR framework was applied to systematically analyze and prioritize supply chain risks. [33]. To delineate the supply chain, we applied the SCOR model, which classifies processes into four fundamental levels: Plan, Source, Make, and Deliver [34][35][36]. This model allowed us to identify specific risk events and their associated root causes. The HOR approach was conducted in two phases. In Phase 1, we ranked risk agents utilizing Aggregate Risk Potential (ARP) values. In Phase 1, the prioritized risk agents were developed, strategies were devised, and the ETD (Effectiveness-to-Difficulty) ratio was assessed. This study aimed to ensure that the strategies were both impact-driven and feasible [5].

Data Collection

Primary data were collected through direct interaction with batik industry stakeholders, consisting of the SME Rinara Batik owner, production staff who are directly involved in daily operations with a minimum of two years of work experience, and an external expert from the Department of Industry and Trade of Cilegon City, using the following techniques:

- **Field Observations:** These were performed at the operational level to provide insights into the day-to-day

- activities and possible supply chain problems [37].
- **Interviews:** Business owners and other employees with relevant roles were participants in semi-structured interviews aimed at uncovering prior risk events, their effects, and the strategies employed to respond to them [38]. They assessed the severity of risk events, the occurrence of risk agents, and the correlation between each risk event and risk agent using a given scale. In addition, they also assessed the correlation between prioritized risk agents and preventive action, as well as the difficulty of preventive action.
- **Brainstorming Sessions:** Expert and stakeholder validation for risk identification, as well as reasonable risk mitigation, was done in group sessions [39].

To further comprehend the batik industry's supply chain, additional internal documents, including flowcharts and operational descriptions, and secondary data were collected. These Southeast Asian resources provided context for our risk analysis process and were, therefore, insightful.

Data Analysis

In the initial phase of the House of Risk (HOR), we systematically identified risk events, their corresponding risk agents, and evaluated them. Each risk event was rated on a scale of 1 to 7, representing the severity of its impact. The frequency of occurrence for each risk agent was measured using the same 1-to-7 scale. To understand how risk agents and events were interrelated, we assigned correlation scores of 0 (no correlation), 1 (weak), 3 (moderate), and 9 (strong). The calculation of the ARP value according to Pujawan and Geraldine [5] is:

$$\mathrm{ARPj} = O_j \sum S_i \times \mathrm{R_{ij}} \quad (1)$$

ARPj = A collection of potential risks from the source/cause of risk (risk agent)

Oj = Risk occurrence level from the source of risk
Si = the degree of a risk's impact (severity level of risk)
Rij = Relationship between risk and head of the risk

All these scores contributed to the calculation of the Aggregate Risk Potential (ARP), which, in turn, assisted in prioritizing the most important risk agents [5]. To make this process more efficient, Pareto analysis was conducted, categorizing the risk agents into two groups: priority (top 80%) and non-priority (remaining 20%) based on the 80/20 principle.

In HOR Phase 2, the work focused on formulating mitigation approaches for the previously defined high-priority risk agents. Each action was evaluated for sufficient mitigation using a correlation scale from 0 to 9 [5]. The Difficulty Degree (Dk) was estimated for each action and scored on a 1-to-5 scale based on feasibility and stakeholder input [6]. With these approaches, Total Effectiveness (TEk) along with the Effectiveness to Difficulty ratio (ETDk) were calculated, which ultimately guided the ranking strategies mitigation. The implementation of preventive actions was prioritized based on the higher ETDk values; this may ensure that the actions have practical and impactful solutions. This approach helps decision-makers allocate limited resources efficiently and focus on mitigation actions that provide the greatest overall benefit to supply chain performance.

Research Location and Duration

The research setting of this study was Rinara Batik, a micro, small, and medium enterprise (MSME) in Cilegon, Banten, Indonesia. The data collection and analysis period ran from January 10 to July 15, 2025, and was sufficient to study the supply chain of this batik business.

Validation

Content validity was ensured through expert validation and relevant documents [40]. The list of risk events, risk agents, and mitigation actions identified during interviews and observations was reviewed in brainstorming sessions involving the SME owner, production staff, and an external expert from the Department of Industry and Trade of Cilegon City. The experts evaluated whether each risk item reflected actual operational conditions and whether the proposed mitigation actions were relevant and feasible.

Construct validity was maintained by using established frameworks (SCOR and HOR) as analytical structures [39] [5]. These frameworks provided predefined parameters for evaluating risk events (severity), risk agents (occurrence), and their relationships (correlation values), ensuring that measurements were consistent with supply chain risk management theory.

RESULT AND DISCUSSION

Rinara Batik is one of the manufacturing-based batik creative industries in Cilegon, Banten. Rinara Batik's supply chain network involves various parties, including suppliers, production units, distributors, and customers. The batik-making process requires raw and supporting materials, such as fabric, naphtol and remasol dyes, soda ash, caustic soda, wax, and waterglass. These materials are supplied by several suppliers located in Java. The availability of these materials is critical to maintaining uninterrupted production activities. To ensure a smooth production process, Rinara Batik plans and controls the flow of raw materials and finished products through a structured production schedule, as illustrated in Figure 1. Rinara Batik also maintains good relationships with stakeholders to support business continuity, operational efficiency and supply chain performance.

This section presents the results of our investigation into supply chain risk management in the context of batik production, concentrating on the identification, prioritization, and mitigation of risks using the integration of the SCOR and HOR method. From a qualitative perspective, this study combines insights from field observations, interviews, and even brainstorming sessions, alongside rigorous quantitative assessments, to offer a holistic understanding of the issues confronting batik producers and provides them with tangible strategies for mitigation.

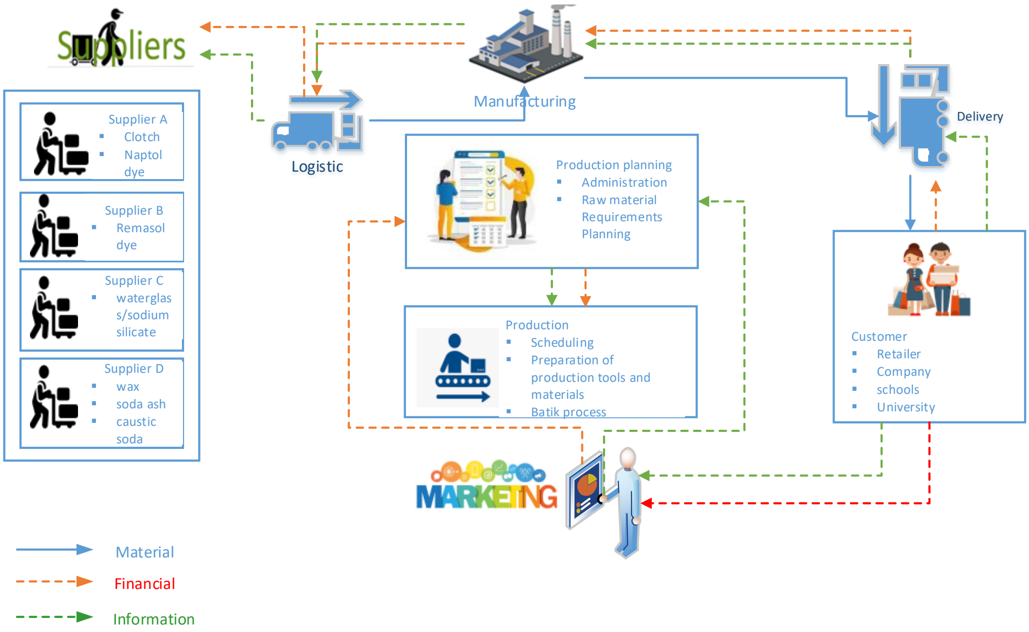

Figure 1. Rinara Batik Supply Chain Network

Risk Event Identification

The supply chain analysis for batik production aimed to uncover disruptions that have, or may, occur in the future within the supply chain [41]. Supply chain issues were addressed through field observations, which provided us with operational insights. Business owners were interviewed in a semi-structured format to provide insights into specific risks, their impacts, and the overall risk profile, which were later validated in brainstorming sessions with other stakeholders. As shown in Table 1, 21 risk events were identified using the SCOR terminology. These risk events represent potential disruptions across different stages of the supply chain. The identified events were then analyzed to determine their severity and underlying causes. This process provided a foundation for prioritizing risks and developing appropriate mitigation strategies. Furthermore, it improved understanding of batik supply chain vulnerabilities. Each risk was analyzed and measured for its impact on operations. Based on the severity rankings, a total of 11 risk events were classified as a moderate impact, as indicated by severity level 2. Additionally, 4 risk events were categorized as a disruption risk with a slightly higher potential impact rated at severity level 3. Also, 1 risk event was classified as a critical disruption at severity level 4, 4 risk events were classified at severity level 5, and 1 risk event was classified at severity level 7. These disruptions identified and pointed to critical disruptions that would have a devastating impact on production efficiency and output quality.

Table 1. Risk Event Identification

Business Process	Activity	Risk Event	Code	Severity
Plan	Planning the purchase of batik raw materials	Unscheduled raw material purchases	E1	5
		Inaccurate determination of the quantity of raw materials to be purchased	E2	3
	Planning the batik production budget	Inaccurate production budget planning	E3	3
	Planning the batik production timeframe	Production schedules that do not go according to plan/target	E4	5
Source	Scheduling the delivery of batik raw materials from suppliers	Late delivery of batik raw materials	E5	7
	Purchase of batik raw materials	Unstable raw material costs	E6	5
	Storage of batik raw materials	Batik raw materials are not stored properly in the warehouse	E7	3
Make	Preparing production tools and materials	Poor fabric quality	E8	2
		Mold growth on wax/wax	E9	2
		Soda Ace is turning into a liquid.	E10	2
		Caustic soda is turning into a liquid.	E11	2
	Batik production process	Fabric sizes and patterns vary	E12	2
		Many wax images are outside the pattern	E13	3
		There are motifs that have not been drawn with wax	E14	2
		There are undyed areas of the fabric	E15	2
		Changes in fabric size	E16	5
		Uneven batik color results	E17	2
	Storage of finished goods	Torn (defective) batik	E18	4
Deliver	Batik order registration	Errors in calculating batik orders	E19	2
	Batik order delivery	Delays in batik delivery	E20	2
Return	Return of rejected products	Additional expenses	E21	2

Risk Agent Identification

To determine the underlying issues associated with vulnerabilities in the supply chain of batik, we found it necessary to determine risk agents, that cause risk events to take place [41]. This process was similar to the identification of risk events, using field observations, interviews with batik owners, and discussions with relevant stakeholders to ensure a comprehensive understanding. From the analysis (see Table 1), we found 13 risk agents, which were all evaluated on the basis of likelihood. There is 1 risk agent with an occurrence rank of 1, 3 risk agents at 2, 5 at 3, 1 risk agent at 4, 2 at 5, and another 1 risk agent at 7 (high likelihood), see Table 2. These findings indicate the likelihood of each risk agent disrupting the supply chain and provide a basis for prioritizing mitigation strategies. Risk agents with higher occurrence scores are more likely to affect multiple supply chain activities. Therefore, they should receive greater attention during risk mitigation planning. The occurrence assessment also complements the severity analysis by identifying both the frequency and potential impact. This combined evaluation provides a basis for prioritizing mitigation efforts and improving supply chain resilience. This approach enables decision-makers to focus resources on the most significant sources of supply chain risk.

Table 2. Risk Agent Identification

No	Risk Agent	Code	Occurrence
1	Sudden additional orders	A1	3
2	Raw material price increases	A2	3
3	Unpredictable weather conditions	A3	5
4	Supplier delays in shipping goods	A4	3
5	Incorrect selection of shipping mode	A5	7
6	Errors in storing raw materials	A6	2
7	Employee negligence	A7	5
8	Purchase of raw materials for reproduction	A8	2
9	Color locking systems that are still grounded (using water glass)	A9	4
10	Limited space for storing raw materials	A10	1
11	Changes in room temperature	A11	3
12	Decreased equipment quality	A12	2
13	Fabric shrinkage after the dyeing and squeezing processes	A13	3

Correlation Between Risk Events and Risk Agents

To explore how risk events and their sources are connected, a correlation analysis was conducted [42]. This process mapped out how each risk agent contributes to specific risk events, using a correlation scale of 0 (no correlation), 1 (weak), 3 (moderate), and 9 (strong). As detailed in the original study, the analysis showed that 6 activities had a weak correlation (scale of 1), 13 activities had a moderate correlation (scale of 3), and 7 activities demonstrated a strong correlation (scale of 9), see Table 3. This correlation matrix offers a clear foundation for prioritizing risk agents, highlighting those with the greatest influence on supply chain disruptions. It also provides a systematic and reliable basis for developing targeted and effective mitigation strategies.

Table 3. Correlation between risk events and risk agents

Risk Event	Code	Risk Agent	Code	correlations
Unscheduled raw material purchases	E1	Sudden additional orders	A1	9
Inaccurate determination of the quantity of raw materials to be purchased	E2	Sudden additional orders	A1	3
Inaccurate production budget planning	E3	Raw material price increases	A2	3
Production schedules that do not go according to plan/target	E4	Sudden additional orders	A1	3
		Unpredictable weather conditions	A3	9
Late delivery of batik raw materials	E5	Supplier delays in shipping goods	A4	3
		Incorrect selection of shipping mode	A5	9
Unstable raw material costs	E6	Raw material price increases	A2	3
Batik raw materials are not stored properly in the warehouse	E7	Limited space for storing raw materials	A10	1
		Errors in storing raw materials	A6	3
Poor fabric quality	E8	Errors in storing raw materials	A6	1
Mold growth on wax/wax	E9	Errors in storing raw materials	A6	1
Soda Ace is turning into a liquid.	E10	Changes in room temperature	A11	9
Caustic soda is turning into a liquid.	E11	Changes in room temperature	A11	9
Fabric sizes and patterns vary	E12	Employee negligence	A7	3
Many wax images are outside the pattern	E13	Decreased equipment quality	A12	3
There are motifs that have not been drawn with wax	E14	Employee negligence	A7	3
		Decreased equipment quality	A12	3
There are undyed areas of the fabric	E15	Employee negligence	A7	1
Changes in fabric size	E16	Fabric shrinkage after the dyeing and squeezing processes	A13	3
Uneven batik color results	E17	Color locking systems that are still grounded (using water glass)	A9	9
Torn (defective) batik	E18	Limited space for storing raw materials	A10	3
		Changes in room temperature	A11	3
Errors in calculating batik orders	E19	Employee negligence	A7	9

Risk Event	Code	Risk Agent	Code	correlations
Delays in batik delivery	E20	Unpredictable weather conditions	A3	1
Additional expenses	E21	Purchase of raw materials for reproduction	A8	1

HOR Phase 1 Calculation

The HOR Phase 1 calculation integrates severity, occurrence, and correlation data to compute the Aggregate Risk Potential (ARP) for each risk agent, enabling prioritization [5]. As shown in Table 4, the risk agent with code A5 (errors in selecting transportation mode/ expedition) recorded the highest ARP value of 441, securing the top priority rank (1), while the risk agent with code A8 had the lowest ARP value of 4, ranked 13. Notably, risk agents A2 and A9 both yielded an ARP of 72, but A2 (rising raw material prices) was prioritized over A9 (ranked 7) due to its critical impact on production costs, as determined through stakeholder input. This prioritization ensures that the most impactful risks are addressed first.

Table 4. HOR Phase 1 Calculation

Risk Event (Ei)	Risk Agent (Aj)													Severity (Si)
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	
E1	9													5
E2	3													3
E3	0	3												3
E4	3		9											5
E5				3	9									7
E6		3												5
E7						3				1				3
E8						1								2
E9						1								2
E10											9			2
E11											9			2
E12							3							2
E13							0					3		3
E14							3					3		2
E15							1							2
E16													3	5
E17									9					2
E18										3	3			4
E19							9							2
E20			1											2
E21								1						2
Occurrence (Oj)	3	3	5	3	7	2	5	2	4	1	3	2	3	
(ARPj)	207	72	235	63	441	26	160	4	72	15	144	30	45	
Priority Rank	3	6	2	8	1	11	4	13	7	12	5	10	9	

Calculation Risk Evaluation

The risk evaluation phase focuses on ranking risk agents based on their ARP values to identify those requiring immediate mitigation. Higher ARP values indicate a greater contribution to supply chain disruptions. This prioritization helps organizations allocate resources more effectively to the most critical risks. As a result, mitigation efforts can be directed toward risk agents with the highest potential impact on supply chain performance. [43]. A Pareto diagram, as depicted in Figure 2. It was used to categorize risk agents into priority (80%) and non-priority (20%) groups, following the 80/20 principle. The priority risk agents, contributing to 80% of the cumulative ARP, include A5 (transportation mode errors), A3 (unpredictable weather), A1 (sudden order increases), A7 (human error), and A11 (room temperature changes). These are associated with the SCOR processes of Source (A5), Plan and Deliver (A3, A1), and Make and Deliver (A7, A11). The non-priority group comprises 8 risk agents (A2, A9, A4, A13, A12, A6, A10, A8), which have a lower cumulative impact. Table 4 lists the priority risk agents, providing a clear focus for mitigation efforts. The results indicate that a small number of risk agents account for most supply chain disruptions. Therefore, addressing these priority risk agents is expected to significantly improve supply chain performance and resilience.

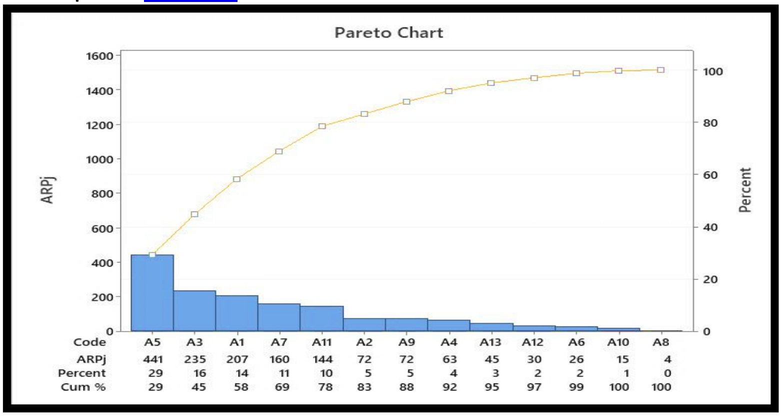

Figure 2. Pareto chart of Risk Agent

Proposed Mitigation Actions

Based on the prioritized risk agents, seven mitigation actions were proposed, as outlined in Table 5. These actions were developed through field observations, interviews, and brainstorming with batik industry experts, ensuring their relevance and feasibility. The proposed actions address critical risks such as transportation errors, weather disruptions, and human errors, aiming to enhance supply chain resilience and operational efficiency.

Table 5. Correlation of Risk Agents with Proposed Mitigation Actions

Risk Agent	Code	Mitigation Action	Code	correlations
Incorrect selection of transportation/shipping mode	A5	Establishing contracts with selected shipping companies	PA1	9
Unpredictable weather conditions	A3	Preparing weather protection materials (tarpaulins)	PA2	9
		Using technology to check the latest weather forecast information	PA3	3
Sudden additional orders	A1	Prioritizing orders using the "first in, first out" principle	PA4	9
Employee negligence	A7	Creating SOPs for stamping and canting	PA5	9
		Providing regular training for workers in stamping and canting production	PA6	3
Changes in room temperature	A11		PA7	1

 http://doi.org/10.30998/ jmil.v10i1.1743

Assessment of Mitigation Action Difficulty

The degree of difficulty (Dk) for implementing each mitigation action was evaluated on a scale of 1 to 5, based on stakeholder input regarding feasibility, resource requirements, and operational constraints [44]. As shown in Table 6, three mitigation actions received a degree of difficulty rank of 1 (low difficulty), three were ranked at 2 (moderate difficulty), and one was ranked at 3 (relatively greater difficulty). This assessment guides the prioritization of actions by balancing effectiveness with implementation feasibility. Actions with lower difficulty ratings can generally be implemented more quickly and with fewer resources. In contrast, actions with higher difficulty ratings may require additional investment, planning, or organizational support. Considering both effectiveness and difficulty ensures that the selected mitigation strategies are practical and achievable for batik SMEs.

Table 6. Assessment of the Level of Difficulty of Implementing Mitigation Actions

Code	Mitigation Actions	Code	Degree of Difficulty (Dk)
A5	Establishing contracts with selected shipping companies	PA1	2
	Preparing weather protection materials (tarpaulins)	PA2	2
A3	Using technology to check the latest weather forecast information	PA3	1
A11	Prioritizing orders using the "first in, first out" principle	PA4	1
	Creating SOPs for stamping and canting	PA5	2
A7	Providing regular training for workers in stamping and canting production	PA6	1
A11	Providing air conditioning	PA7	3

HOR Phase 2 Calculation

HOR Phase 2 evaluates the proposed mitigation actions by calculating their Total Effectiveness (TEk) and Effectiveness-to-Difficulty ratio (ETDk) [5]. As presented in Table 7, the mitigation action with code PA1 (establishing contracts with selected expeditions) achieved the highest TEk of 3969 and ETDk of 1984.5, indicating its high effectiveness and relatively low implementation difficulty. Conversely, action PA7 (providing room cooling equipment) had the lowest TEk of 144 and ETDk of 48, reflecting lower effectiveness or greater difficulty. These metrics ensure that mitigation actions are prioritized based on their potential impact and feasibility.

Table 7. HOR Phase 2 Calculation

To be a Treated Risk Agent (Aj)	Code	Preventive Action (PAk)							(ARPi)
		PA1	PA2	PA3	PA4	PA5	PA6	PA7	
Incorrect selection of shipping mode	A5	9	0	0	0	0	0	0	441
Unpredictable weather conditions	A3	0	9	3	0	0	0	0	235
Sudden additional orders	A1	0	0	0	9	0	0	0	207
Employee negligence	A7	0	0	0	0	9	3	0	160
Changes in room temperature	A11	0	0	0	0	0	0	1	144
Total Effectiveness of Action k (TEk)		3969	2115	705	1863	1440	480	144	
Degree of Difficulty Ratio (Dk)		2	2	1	1	2	1	3	
Effectiveness to Difficulty Ratio (ETDk)		1984.5	1057.5	705	1863	720	480	48	

To be a Treated Risk Agent (Aj)	Code	Preventive Action (PAk)							(ARPi)
		PA1	PA2	PA3	PA4	PA5	PA6	PA7	
Rank of Priority (Rk)		1	3	5	2	4	6	7	

Prioritization of Mitigation Actions

The final step ranks mitigation actions based on their ETDk values to guide implementation, as shown in Table 8. The prioritized actions, in descending order of ETDk, are: (1) establishing contracts with expeditions (PA1), (2) prioritizing orders using First-In-First-Out (PA4), (3) preparing weather-protective materials (e.g., tarpaulin) (PA2), (4) developing standard operating procedures (SOPs) for stamping and dyeing (PA5), (5) using technology (e.g., mobile phones) for real-time weather updates (PA3), (6) providing regular training for workers in stamping and dyeing (PA6), and (7) providing room cooling equipment (PA7). This ranking helps SMEs prioritize effective and feasible mitigation strategies, improving supply chain resilience, operational performance, and decision-making.

Table 8. Priority Ranking of Mitigation Actions

Mitigation Actions	Code	Rank	Tek	Dk	ETDk
Establishing cooperation contracts with selected shipping companies	PA1	1	3.969	2	1.984,5
Prioritizing orders using the "First in, First out" principle	PA4	2	1.863	1	1.863,0
Preparing weather protection materials (tarpaulins)	PA2	3	2.115	2	1.058
Creating SOPs for stamping and canting	PA5	4	1.440	2	720
Using technology to check the latest weather forecast information	PA3	5	705	1	705
Providing regular training for workers in stamping and canting	PA6	6	480	1	480
Providing air conditioning	PA7	7	144	3	48

Discussion (Findings and Comparison with Related Studies)

The study identified 21 risk events and 13 risk agents in the batik supply chain as described in Table 4, which were evaluated based on their severity. One risk event reached a severity rating of 7, indicating a major operational threat. Meanwhile, the risk agents, including errors in selecting transportation modes (A5) and unpredictable weather (A3), were ranked using the Aggregate Risk Potential (ARP) in Phase 1. Notably, A5 scored the highest ARP of 441 (see Table 3). A Pareto analysis (Figure 2) identified five key risk agents: A5, A3, A1 (sudden order surges), A7 (human error), and A11 (temperature fluctuations) as top priorities.

In Phase 2, seven mitigation strategies were proposed (Table 5), and each was prioritized based on its Effectiveness-to-Difficulty ratio (ETDk), as shown in Table 8. The highest-ranked strategy, forming contracts with selected shipping providers (PA1, ETDk = 1984.5), directly addresses transportation-related risks, a major concern given the industry's reliance on external suppliers. Other key actions include implementing a First-In-First-Out system for managing orders (PA4) to handle demand volatility and providing training for workers (PA6) to reduce human error. The lowest-ranked action, installing cooling equipment to regulate room temperature (PA7, ETDk = 48), was likely deprioritized due to high costs, a common constraint for SMEs. These findings show that batik supply chain risks stem from external, environmental, and operational factors, while the HOR approach helps identify practical mitigation strategies for SMEs.

Transportation and weather-related risks are consistent with earlier findings by Chopra and Sodhi [42]. However, batik SMEs are more vulnerable due to limited resources and less formal logistics systems. Instead, they rely on informal partnerships and localized distribution networks, making them more vulnerable to transportation disruptions. Similarly, Tang [4] highlighted weather-related risks in textile supply chains. This study further shows that weather affects both logistics and dyeing quality, creating operational and environmental risks for batik SMEs. This study's application of the HOR framework originally developed by Pujawan and Geraldin [5] sets it apart from other risk management models. For instance, Kleindorfer and Saad [6] focused on managing rare but high-impact disruptions in large enterprises. In contrast, the HOR method's two-phase structure, using ARP to prioritize risks and ETDk to rank mitigation actions, proved well-suited to the batik sector, much like its previous success in other SME manufacturing contexts [5]. Importantly, this study expands the use of HOR to an industry with deep cultural roots, addressing a gap identified by Sodhi *et al.* [12], who called for risk frameworks tailored to specific industries. This study extends the use of HOR to the batik industry, identifying transportation and weather risks as key priorities and emphasizing logistics partnerships as an important mitigation strategy.

Jüttner *et al.* [41] categorized supply chain risks into operational, external, and network-related risks. While their work was largely theoretical, this study provides practical mitigation strategies for batik SMEs. Wagner and Bode [8] highlighted the impact of transportation and supplier risks on performance, supporting the prioritization of A5. However, batik SMEs are more vulnerable due to their dependence on external logistics providers. Manuj and Mentzer [9] discussed cultural and logistical risks in global supply chains, while this study focuses on regional constraints affecting batik production in Indonesia. Christopher and Peck [45] advocated proactive risk identification to strengthen supply chain resilience, consistent with this study's approach. Similarly, Rao and Goldsby [11] explored environmental and process risks similar to those of A3 and A7, though their risk classification did not extend to traditional industries like batik. Blackhurst *et al.* [13] introduced disruption identification methods similar to this study's approach, but focused on general manufacturing rather than culturally specific industries. Thun and Hoenig [14] applied risk management to the automotive sector and highlighted the need for tailored strategies, but the specialized processes in batik, such as the sensitivity of dyes to temperature, demand a different approach. Tummala and Schoenherr [15] emphasized structured risk management, supporting the use of HOR in this study. The findings also highlight the need for external coordination and context-specific risk management in traditional SMEs.

Contributions and Implications

This study applies the SCOR and HOR frameworks to the batik supply chain, identifying key risks and proposing practical mitigation strategies. It introduces an integrated SCOR-HOR framework and highlights the importance of worker skills, environmental conditions, supplier relationships, logistics partnerships, and workforce development in managing supply chain risks in batik SMEs. It applies the HOR framework, demonstrating its adaptability to traditional craft-based industries [16]. The findings provide practical recommendations, while the SCOR-HOR framework offers a flexible and structured approach to risk mitigation for batik SMEs and similar industries.

CONCLUSION

This study aimed to identify and manage supply chain risks in batik SMEs using the SCOR and HOR frameworks. A mixed-methods approach combining stakeholder input and quantitative risk assessment was used to develop practical and data-driven mitigation strategies. As a result, 21 risk events and 13 risk agents were identified in the batik supply chain (see Table 3). The main risks identified were incorrect transportation selection, weather conditions, increased customer demand, operational errors, and unstable room temperature. To address these risks, seven mitigation strategies were proposed and prioritized using the ETDk ratio (see Table 8). The highest-priority mitigation strategy was establishing formal contracts with logistics providers (ETDk = 1984.5), while providing room cooling equipment received the lowest priority (ETDk = 48). The findings highlight the importance of logistics partnerships, workforce training, and environmental control in reducing batik supply chain risks. The integrated SCOR-HOR framework provides a practical approach for batik SMEs and similar traditional industries. Future research should expand to other regions and explore advanced methods such as simulation and machine learning.

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