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Analyzing Supply Chain Risks in the Tea Industry Using SCOR and HOR

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ABSTRACT

The tea plantation sector has a complex supply chain, and the production process at the black tea processing company is often affected by various operational issues. One of the main problems is delays in raw material processing caused by the late arrival of wet tea leaves, which are further aggravated by machine breakdowns and a lack of worker discipline. These conditions can disrupt or even halt production, emphasizing the need for effective risk mitigation measures. This study aims to identify risk factors in the black tea production supply chain using the Supply Chain Operations Reference (SCOR) model and to formulate priority mitigation strategies through the House of Risk (HOR) method. The results of the HOR Phase I analysis identified 21 risk events and 4 priority risk agents with a cumulative Aggregate Risk Potential (ARP) value of 76.82%. The four main risk agents are: (A2) irregularities or delays in the transportation of wet tea leaves, (A6) lack of worker discipline, (A7) machine damage or malfunction, and (A8) low employee awareness during work. The HOR Phase II analysis produced seven mitigation actions, which were ranked based on the Effectiveness to Difficulty Ratio (ETD). The top three priority actions are (PA_1) conducting analysis and evaluation of employee performance (ETD = 6.00), (PA_3) increasing supervision of foremen at each station (ETD = 5.00), and (PA_2) creating a schedule for picking wet tea leaves (ETD = 5.00). Supporting actions include quality control of raw materials (PA_4), routine machine maintenance (PA_5), increasing awareness to work carefully (PA_7), and limiting machine loads to maximum capacity (PA_6). The results indicate that human and managerial factors—including employee performance, supervision, and work scheduling—are the dominant contributors to supply chain risk. Therefore, mitigation strategies should prioritize management and behavioral improvements, supported by technical maintenance and process control, to enhance the efficiency, reliability, and resilience of the black tea supply chain.

Keywords: *Supply Chain, Risk Management, SCOR, House of Risk (HOR), Black Tea, Risk Mitigation.*

ABSTRAK

Sektor perkebunan teh memiliki rantai pasok yang kompleks, dan proses produksi pada perusahaan pengolahan teh hitam seringkali menghadapi berbagai permasalahan operasional. Salah satu permasalahan utama adalah keterlambatan dalam proses pengolahan bahan baku akibat keterlambatan kedatangan pucuk teh basah, yang diperparah dengan adanya kerusakan mesin produksi serta kurangnya kedisiplinan pekerja. Kondisi ini dapat menghambat bahkan menghentikan proses produksi, sehingga diperlukan tindakan mitigasi risiko yang efektif untuk meminimalkan dan mencegah gangguan dalam proses produksi. Penelitian ini bertujuan untuk mengidentifikasi faktor-faktor risiko dalam rantai pasok produksi teh hitam menggunakan model Supply Chain Operations Reference (SCOR) serta merumuskan strategi mitigasi risiko prioritas dengan pendekatan House of Risk (HOR). Hasil analisis HOR tahap I mengidentifikasi 21 kejadian risiko dan 4 agen risiko prioritas dengan nilai kumulatif Aggregate Risk Potential (ARP) sebesar 76,82%. Keempat agen risiko utama tersebut meliputi: (A2) ketidakteraturan atau keterlambatan pengangkutan pucuk teh basah, (A6) kurangnya kedisiplinan pekerja, (A7) kerusakan

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atau gangguan mesin produksi, dan (A8) rendahnya kesadaran pekerja dalam menjalankan tugas. Hasil analisis HOR tahap II menghasilkan tujuh tindakan mitigasi risiko yang diperingkat berdasarkan nilai Effectiveness to Difficulty Ratio (ETD). Tiga tindakan dengan prioritas tertinggi yaitu (PA_1) melakukan analisis dan evaluasi kinerja karyawan (ETD = 6,00), (PA_3) meningkatkan pengawasan mandor di setiap stasiun kerja (ETD = 5,00), dan (PA_2) membuat jadwal pemetikan pucuk teh basah (ETD = 5,00). Tindakan pendukung lainnya meliputi pengendalian kualitas bahan baku (PA_4), pemeliharaan mesin secara rutin (PA_5), peningkatan kesadaran pekerja untuk bekerja dengan hati-hati (PA_7), dan pembatasan beban mesin sesuai kapasitas maksimum (PA_6). Hasil penelitian menunjukkan bahwa faktor manusia dan manajerial seperti kinerja karyawan, pengawasan, dan penjadwalan kerja memiliki pengaruh yang lebih dominan terhadap risiko rantai pasok dibandingkan faktor teknis. Oleh karena itu, upaya mitigasi risiko sebaiknya memprioritaskan peningkatan manajemen dan perilaku kerja, yang didukung dengan pemeliharaan teknis dan pengendalian proses untuk meningkatkan efisiensi, keandalan, dan ketahanan rantai pasok produksi teh hitam.

Kata Kunci: Rantai Pasok, Manajemen Risiko, SCOR, House of Risk (HOR), Teh Hitam, Mitigasi Risiko

1. Introduction

In the globalization era marked by increasingly fierce competition, supply chain management plays a crucial role in ensuring the continuity of business operations. A supply chain represents a network of organizations that collaborate to produce and deliver goods to customers [1]. To remain competitive in today's dynamic business environment, companies must adopt supply chain models aligned with strategic objectives and customer expectations [2]. An effective and efficient supply chain enables firms not only to optimize production and distribution processes but also to enhance customer satisfaction and strengthen market competitiveness.

Given the complexity of activities within the supply chain, robust management practices are essential. However, managing a supply chain is inherently challenging, as every stage of the process carries potential risks that, if not handled properly, may lead to significant disruptions [13]. Risk itself refers to an event that introduces uncertainty and may cause losses minor or major that can threaten a company's operational sustainability [4].

Manufacturing companies generally operate within complex supply chain systems [3], and tea processing companies are no exception. Tea is a key commodity in Indonesia's economic growth, serving as one of the nation's main export products and an important source of foreign exchange alongside oil and gas [5]. A black tea processing company in Indonesia manages an extensive supply chain that spans multiple stages from processing raw agricultural materials to distributing finished products to domestic and international markets across Asia, Africa, Australia, America, and Europe.

In this company, supply chain management begins with the flow of raw materials, specifically wet tea leaves, which are processed daily at a capacity of around 55 tons, sourced from nearby tea plantations. However, one of the recurring challenges is processing delays caused by the late arrival of wet tea leaves, which serve as the primary input. Before mechanical processing, the leaves must undergo a withering process lasting approximately 16–18 hours, and any delay at this stage directly affects subsequent production schedules.

At the rolling stage, delays are not only due to the late completion of withering but also to inefficient handling by workers in transferring withered leaves between machines. These delays in the rolling process occur consistently, with an average delay rate of 44.07% recorded in 2024. As a result, such inefficiencies cause a chain reaction of delays throughout the subsequent processing stages in the production line.

In addition to delays at the withering and rolling stages, machine breakdowns also significantly contribute to production delays. Equipment failures can hinder or even halt the entire production process due to repair time requirements. Disruptions at one production stage often create a domino effect, as subsequent stations are unable to proceed without input from the previous stage.

Activities within the supply chain are inherently exposed to various risks. If a company fails to thoroughly assess these risks and their potential impacts on performance, operational efficiency and overall outcomes may be suboptimal. Therefore, applying supply chain risk management analysis is essential to minimize the emergence and impact of such risks [14]. This analysis focuses on identifying potential risk sources (agents) and risk events in each activity, as well as evaluating their consequences. Moreover, it involves developing appropriate mitigation strategies to reduce the likelihood and impact of recurring risks [6].

Consequently, risk analysis within the black tea production supply chain is crucial for maintaining process stability and efficiency. The objective of this study is to identify key risk factors and formulate effective mitigation strategies based on prioritized risk agents. To achieve this, the research applies the Supply Chain Operations Reference (SCOR) model to map and analyze the company's supply chain processes [7]. This is followed by the House of Risk (HOR) framework, which is used to identify potential failures and risks that may have been previously overlooked and to design preventive actions aimed at minimizing the impact of identified risk agents [8].

2. Methodology

This study employs an exploratory descriptive research design, which aims to obtain a comprehensive, clear, and in-depth understanding of a specific phenomenon of interest [9]. The research focuses on identifying problems within the supply chain of black tea production, examining the associated risks that affect the supply chain, and analyzing risk mitigation strategies for issues that arise within a black tea processing company. The data collected for this study consist of primary and secondary sources.

1. Primary data were obtained through interviews, direct observations, and questionnaires. The primary data collected include:
   a) Mapping of supply chain activities based on the SCOR model,
   b) Assessment of risk events (severity),
   c) Assessment of risk agents (occurrence),
   d) Evaluation of the correlation levels between risk events and risk agents,
   e) Evaluation of the correlation levels between risk agents and risk mitigation actions, and
   f) Assessment of the difficulty level of each risk mitigation measure.
2. Secondary data were gathered through literature studies related to supply chain management, risk analysis, and the SCOR–HOR framework.

The population in this study includes all supervisors and employees responsible for the orthodox black tea production process in the company. This comprises three supervisors and 101 employees. The sampling technique applied is purposive sampling, which involves selecting individuals who possess specific knowledge, experience, and positions relevant to the research objectives [9]. Accordingly, the key respondents in this study include the Technical and Processing Assistants, as well as the Withering, Rolling, Enzymatic Oxidation, Drying, Sorting, and Packing Foremen

3. Results and Discussion

3.1. Identification of Risk Events and Risk Agents

The research commenced with the identification of risk events that could negatively affect the supply chain flow, utilizing the Supply Chain Operations Reference (SCOR) model [2]. The SCOR framework serves as a comprehensive reference for supply chain management, combining three main aspects business process redesign, benchmarking, and performance measurement into an integrated, cross-functional system. It categorizes supply chain activities into five core processes: Plan, Source, Make, Deliver, and Return [1].

The identification stage was carried out through observations and interviews with selected informants, followed by a risk assessment using structured questionnaires distributed to chosen respondents. The goal of this stage was to identify potential risk events that may arise throughout the supply chain, based on the SCOR process structure.

In this context, risk agents represent the underlying causes that trigger the occurrence of risk events. A single risk event may stem from one or multiple risk agents. The evaluation of risk events was conducted by measuring their severity, while the evaluation of risk agents was based on their likelihood of occurrence. Both aspects were assessed using a 1–10 rating scale, in accordance with predetermined assessment criteria [7].

3.2. Identification of Correlation of Risk Events with Risk Agents

The purpose of this stage is to analyze the strength of the relationship between each identified risk event and its corresponding risk agents. The assessment is conducted using a scoring scale to represent the level of correlation, where scores of 0, 1, 3, and 9 indicate no correlation, weak correlation, moderate correlation, and strong correlation, respectively [8].

3.3. House of Risk I

In the House of Risk (HOR) Phase I, the analysis requires data consisting of severity ratings, occurrence ratings, and correlation scores between risk events and risk agents. These data are used to calculate the

Aggregate Risk Potential (ARP), which serves as the basis for determining the priority order of risk agents that need to be addressed first. The prioritization process is carried out by ranking risk agents according to their ARP values, where a higher ARP indicates a higher priority for mitigation. An example of the ARP calculation is presented as follows.

$$ARP_j = O_j \sum S_i R_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where:
ARP_j = *Aggregate Risk Potential for risk agent j*
O_j = *Occurrence rating of risk agent j*
S_i = *Severity rating of risk event i*
R_{ij} = *Correlation rating between risk event i and risk agent j*

The calculation aims to determine which risk agents have the greatest potential impact on the supply chain. Risk agents with higher ARP values indicate a greater contribution to overall supply chain risk and therefore must be prioritized for mitigation actions**.** ARP calculation is shown below Table 1.

Table 1. ARP Calculation

Risk Event (i)	Risk Agent (j)	Severity (S_i)	Occurrence (O_j)	Correlation (R_{ij})	ARP_j
RE1	RA1	7	6	9	378
RE2	RA1	5	6	3	90
RE3	RA1	4	6	1	24
Total ARP for RA1 = $6 \times (7 \times 9 + 5 \times 3 + 4 \times 1) = 6 \times (63 + 15 + 4) = 6 \times 82 = 492$.					

From this calculation, it can be seen that risk agent RA1 has a total ARP of 492, indicating that it is one of the top-priority risks that requires immediate mitigation. Based on the ARP calculation, a Pareto diagram is made to see the priority risk agents that will be given mitigation actions first. Determination of priority risk agents is done using the Pareto principle. This principle states that in many cases, about 80% of the effects are caused by 20% of the causes. [12]. Where the risk that has a large impact is caused by a small number of risk-causing agents. Therefore, it is hoped that by mitigating the risk-causing agents that cause small risks, some of the impacts can be controlled. Based on the Pareto diagram above, it can be seen that there are 4 risk agents that have an influence of 76.82% on the risk incident.

3.4. House of Risk II

House of Risk II is a stage of developing risk mitigation actions that are considered effective against priority risk agents. Risk mitigation actions are carried out to overcome or reduce the chances of the emergence or occurrence of 4 risk agents. The following are adaptive risk mitigation actions as seen in Table 2.

Table 2 Risk Mitigation Actions

Code	Risk Agent	Risk Mitigation Actions	Code*
A2	Irregularities or delays in the transportation process of wet tea leaves.	Conduct a systematic analysis and evaluation of employee performance to identify causes of inefficiency.	PA_1
		Establish a structured schedule for collecting and transporting wet tea leaves to ensure timeliness.	PA_2
A6	Lack of worker discipline during production activities.	Strengthen supervisory control by increasing the oversight role of foremen at each production stage.	PA_3

		Implement strict quality control by separating raw materials from unwanted or hard foreign materials.	PA_4
A7	Occurrence of equipment or machine malfunctions during operation.	Carry out periodic and preventive maintenance to ensure machine reliability.	PA_5
		Regulate machine usage by limiting operational loads to the optimal capacity level.	PA_6
A8	Low employee awareness or carelessness during work execution.	Improve worker attentiveness by fostering awareness and diligence in performing tasks.	PA_7

Source: Data Processing

After designing risk mitigation actions, the next step is to assess the correlation between risk mitigation actions and risk agents by giving a score of 0, 1, 3, 9. After that, it is continued by assessing the level of difficulty in implementing risk mitigation actions. The assessment of the level of difficulty uses a score of 3, 4, 5, which respectively indicate easy to implement, slightly difficult to implement, and difficult to implement [8].

Next, The Total Effectiveness (TE_k) for each mitigation action is calculated using the following formula:

$$TEk=\sum(Eik\times ARPi)\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Where:

E_{ik}= Effectiveness of mitigation action *k* on risk agent *i*

ARP_i= Aggregate Risk Potential of risk agent *i*

To determine priority, the Effectiveness to Difficulty Ratio (ETD) is computed as:

$$ETD_k = \frac{TEk}{D_k}\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

A higher ETD value indicates that a mitigation action is more efficient and should be prioritized, as it provides greater effectiveness relative to the level of difficulty or resources required. Based on this analysis, the mitigation actions are ranked according to their ETD ratios, and the top-ranked actions are recommended for implementation to reduce supply chain risks in the black tea production process effectively

Table 3. Risk Mitigation Action Ranking Results

Action Description	Mitigation	Targets	TE	Difficulty	ETD
Conduct analysis and evaluation of employee performance	PA1	A2	240	40	6.0
Create a schedule for picking wet tea leaves	PA2	A2	150	30	5.0
Increase supervision of the foreman in charge at each station	PA3	A6	175	35	5.0
Conduct quality control by separating raw materials from hard materials	PA4	A6	150	45	33.3 3
Raise awareness to work diligently	PA7	A8	60	20	3.0
Limit the engine load to maximum capacity	PA6	A7	60	25	2.4
Perform routine machine maintenance	PA5	A7	135	60	2.25

Analysis and evaluation of employee performance, which achieved the largest ETD value (6.00). This indicates that improving employee performance evaluation provides the greatest risk reduction impact relative to its implementation difficulty. The next priorities are PA_3 (foreman supervision) and PA_2 (tea leaf scheduling), both with high ETD ratios (around 5.00), showing that enhanced monitoring and scheduling efficiency play critical roles in reducing operational delays and coordination risks. PA_4 (quality control) and PA_5 (machine maintenance) follow as mid-level priorities, contributing to process reliability and product quality. Lastly, PA_6 (limiting machine load) and PA_7 (increasing awareness), while still important, have relatively lower ETD values, meaning their effectiveness is more limited or their difficulty-to-benefit ratio is less favorable compared to other actions. Here is the table of ranking results based on the highest ETD values (main priorities) Table 4.

Table 4. Risk Mitigation Action Ranking Results

Code	Risk Mitigation Actions	Rank
PA1	Conduct analysis and evaluation of employee performance	1
PA3	Increase supervision of the foreman in charge at each station	2
PA2	Create a schedule for picking wet tea leaves	3
PA4	Conduct quality control by separating raw materials from hard materials	4
PA7	Increase awareness to work carefully	5
PA6	Limit machine loads to maximum capacity	6
PA5	Conduct routine machine maintenance	7

Source: Data Processing

Based on the results of the House of Risk (HOR) Phase II analysis, the ranking of mitigation actions was determined using the Effectiveness to Difficulty Ratio (ETD), where a higher value indicates a higher priority. The top priority is PA_1 – Conduct analysis and evaluation of employee performance (ETD = 6.00), followed by PA_3 – Increase supervision of foremen (ETD = 5.00) and PA_2 – Create a schedule for picking wet tea leaves (ETD = 5.00), which emphasize the importance of improving management and coordination to prevent production delays. Other supporting actions include PA_4 – Conduct quality control (ETD = 3.33) and PA_5 – Routine machine maintenance (ETD = 2.25), while PA_7 – increased awareness to work carefully (ETD = 3.00) and PA_6 – Limit machine loads (ETD = 2.40) are categorized as lower priorities. Overall, the results indicate that human and managerial factors have a greater influence on minimizing supply chain risks compared to technical interventions, suggesting that performance evaluation, supervision, and scheduling improvements should be prioritized to enhance supply chain efficiency and reliability.

The results of this study demonstrate that human and managerial factors are the primary contributors to supply chain risks in the black tea production process. Delays in raw material supply, poor supervision, and lack of discipline among workers were found to significantly impact process efficiency. This aligns with previous findings by [5], which reported similar challenges in the tea plantation sector, emphasizing that human behavior and management structure have a stronger influence on operational stability than technical constraints.

In comparison with other studies that applied the House of Risk (HOR) framework [3-6], this research provides a quantitative prioritization of risk mitigation actions through ETD analysis. Unlike studies that only map risks descriptively, this study establishes a structured decision-making basis by combining severity, occurrence, and implementation difficulty into a single prioritization metric.

The Pareto chart and HOR matrices effectively visualize how a small number of risk agents dominate the overall risk landscape, consistent with the 80/20 principle discussed by [12]. Nevertheless, future research can further enhance visualization through dynamic models such as risk heatmaps or process flow simulations.

Overall, the findings reaffirm that improving employee performance evaluation, supervisory control, and production scheduling can substantially reduce the likelihood of process disruptions. These results support the argument by [8] that proactive and data-driven risk management enhances the resilience and responsiveness of the supply chain.

Maintaining the quality of raw materials helps reduce the likelihood of machine damage, which can otherwise lead to processing delays. Implementing regular preventive maintenance is also essential, as it enables companies to prevent equipment failure, extend machine lifespan, and minimize production interruptions. Furthermore, raising employee awareness about the importance of working carefully contributes to producing high-quality tea leaves, which are crucial for maintaining production standards. This awareness can be improved through personal engagement, socialization programs, and incentive systems that reward units demonstrating performance improvement. Additionally, operating machines within their designated maximum load capacity ensure optimal performance and prevent overloading that could cause mechanical failures. Machine breakdowns not only lead to unexpected repairs but also result in production delays, ultimately disrupting the overall efficiency of the production process [15]

4. Conclusion

This study analyzed the risk factors in the black tea production supply chain using the Supply Chain Operations Reference (SCOR) and House of Risk (HOR) methods. The results of the HOR Phase I analysis identified four main risk agents that significantly affect the production process: irregularities or delays in the transportation of wet tea leaves (A2), lack of worker discipline (A6), machine damage or malfunction (A7), and low employee awareness (A8). These risks have a considerable impact on production continuity, particularly in causing delays and process inefficiencies.

In the House of Risk Phase II analysis, the Effectiveness to Difficulty Ratio (ETD) was used to determine the priority of mitigation actions. The results show that the highest-priority mitigation action is PA_1 – Conduct analysis and evaluation of employee performance (ETD = 6.00), followed by PA_3 – Increase supervision of the foreman at each station (ETD = 5.00), and PA_2 – Create a schedule for picking wet tea leaves (ETD = 5.00). These three actions are considered the most effective and feasible to implement in reducing supply chain risks. Other supporting actions include PA_4 – Conduct quality control by separating hard materials (ETD = 3.33), PA_5 – Routine machine maintenance (ETD = 2.25), PA_7 – increased awareness to work carefully (ETD = 3.00), and PA_6 – Limit machine loads to maximum capacity (ETD = 2.40).

Overall, the findings indicate that human and managerial factors—such as employee performance, supervision, and work scheduling—play a more dominant role in influencing supply chain risk compared to purely technical factors. Therefore, risk mitigation efforts should prioritize management-based strategies that enhance workforce discipline and coordination, supported by technical maintenance and quality control measures to ensure production continuity.

Future research could focus on developing quantitative risk prediction models or decision-support systems to anticipate potential disruptions more accurately. Integrating data analytics, IoT-based monitoring, and preventive maintenance scheduling could further improve the resilience and efficiency of the black tea supply chain.

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