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Supply Chain Risk Management Analysis Using the House of Risk (HOR) and Analytical Network Process (ANP) at PT XYZ

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ABSTRACT

The supply chain in the quartz sand mining and processing industry is characterized by a high level of uncertainty, which increases the potential for operational disruptions if risks are not properly managed. At PT XYZ, various risks occur across supply chain activities, including planning, mining, processing, and distribution, which contribute to significant gaps between production targets and actual production outcomes. Therefore, effective supply chain risk management is required to improve operational stability and production performance. This study aims to identify supply chain risks and determine priority mitigation strategies at PT XYZ. The research integrates the Supply Chain Operations Reference (SCOR) model, the House of Risk (HOR) method, and the Analytical Network Process (ANP) with the Benefit, Opportunity, Cost, and Risk (BOCR) criteria. Data were collected through field observations, interviews, Focus Group Discussions (FGDs), and questionnaires. The results identified 23 risk events and 23 risk agents within the supply chain activities. Based on the 80/20 Pareto analysis, 14 critical risk agents were prioritized for mitigation. The HOR Phase 2 analysis generated 14 mitigation strategies, where strategy PA9 achieved the highest Effectiveness-to-Difficulty Ratio (ETDk) score of 3582. Furthermore, the ANP analysis indicates that Alternative 1 (PA9) has the highest priority weight of 0.12623, followed by Alternative 2 (PA3) with a weight of 0.11040 and Alternative 3 (PA1) with a weight of 0.10401. These findings provide practical recommendations for PT XYZ to reduce critical supply chain risks, improve operational readiness, and enhance overall supply chain performance.

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INTRODUCTION

The development of industry in Indonesia has progressed rapidly in line with advancements in science and technology, particularly in the manufacturing sector (Ardiansyah & Nugroho, 2023). Companies are required to remain competitive within their respective industries due to the increasingly intense level of competition. The supply chain sector is one of the most crucial aspects in determining a company's ability to sustain its business operations. To achieve more efficient integration across different organizations, Supply Chain Management is applied, involving suppliers, manufacturers, distributors, retailers, and customers (Nasution &

Aslami, 2022). However, numerous risks exist within supply chain processes that may disrupt the flow of operations and lead to inefficiencies. As a result, managing risks is crucial for minimizing both the impact and the probability of these risks (Anindyanari & Puspitasari, 2023).

Located in Tuban Regency, East Java, PT XYZ operates in the mining and processing of quartz sand. Quartz sand is a non-metallic mineral commodity with high economic value, as it is widely used as a raw material in the glass, cement, ceramics, metal casting, and chemical industries. With abundant quartz sand reserves in the Tuban region, PT XYZ plays a significant role in supporting industrial raw material needs and maintaining the continuity of the industrial supply chain in Indonesia.

In its operations, PT XYZ faces various supply chain challenges that have resulted in a significant gap between production targets and actual output. Production data from October 2024 to September 2025 indicate that the company set an annual target of 24,000 tons; however, the actual production achieved was only 8,699 tons, representing approximately 36% of the annual target. Furthermore, monthly production performance shows considerable fluctuations, with achievement levels ranging from 18% to 82% of the monthly targets. This condition indicates the presence of disruptions within supply chain activities that have not been effectively managed.

The problem is influenced by several key factors. From the mining side, limited access points have become a significant constraint. Previously, two access openings were available to facilitate the mining process; however, only one remains, making material access more restricted. The increasing distance to the sand source also adds to the challenge, as the hauling process requires more time and higher costs. This condition leads to wasted time and underutilized work capacity, resulting in decreased productivity, even though the transported material still reaches the processing stage.

In addition to technical factors, the company also experiences dependency on subcontractors as providers and transporters of raw materials for production. This dependency arises because the transportation of silica sand from the mining area to the processing site is entirely carried out using the subcontractors' fleet, rather than the company's own equipment. As a result, when subcontractors face delays, shortages of fleet units, or coordination issues, the material supply process to the production area is also disrupted. This is consistent with the study by Safitriani & Nugraha, (2020), which, in a case study of PT Berau Coal, found that dependency on raw material suppliers is one of the causes of slow production performance. Furthermore, raw material supply risks, such as material shortages and failure to deliver on time, are also identified by Kesuma & Kusumastuti, (2024) as major factors disrupting the continuity of mining supply chain operations in Indonesia.

Thus, the problems faced by PT XYZ are not only technical in nature but are also influenced by external factors that further weaken supply chain stability. This is in line with the findings of Prasetyo dkk., (2022), which state that mining company supply chains in Indonesia are highly vulnerable to operational, technical, and external risks that directly affect production and distribution performance. This is also supported by the study of Kusmana dkk., (2021), which emphasizes that the mismatch between planning targets and actual mining conditions is a major factor that increases operational risk in the mining supply chain.

To address these issues, this study employs a combined approach of Supply Chain Operations Reference (SCOR), House of Risk (HOR), and Analytic Network Process (ANP). SCOR is used to comprehensively map all supply chain activities within the company (Asrory dkk., 2024), while HOR is applied to identify and prioritize the most critical risks (Prasetyo dkk., 2022). HOR Phase 1 focuses on identifying risk agents and determining their priority levels as a basis for mitigation actions. Meanwhile, HOR Phase 2 aims to formulate risk mitigation strategies based on the calculation of Aggregate Risk Potential obtained from HOR Phase 1 (Sofiana dkk., 2025). Furthermore, the ANP method is utilized as a decision-making tool that considers the interdependencies among strategic objectives (Natalia dkk., 2021). The prioritization of risk mitigation strategies in ANP is determined by integrating the results from HOR Phase 2 with ANP weighting values. Strategies with the highest scores are selected as the top priority mitigation actions to be implemented by the company (Sofiana dkk., 2025).

Through this approach, the study is expected to provide practical contributions to PT XYZ in formulating effective and sustainable supply chain risk mitigation strategies. Compared to previous studies, such as Safitriani & Nugraha, (2020), which primarily emphasize supplier dependency analysis without integrating comprehensive risk mapping, and Kesuma & Kusumastuti, (2024), which focus on raw material supply risks without considering interrelationships among risks, this study offers a more integrated perspective. Additionally, prior studies by (Defriyanti & Ernawati, 2021) and Ulfah, (2020) only combine SCOR and HOR in identifying and mitigating risks without accounting for the complex interdependencies among alternative strategies. Therefore, the novelty of this research lies in the integration of SCOR, HOR, and ANP simultaneously to capture the interrelationships and dependencies among mitigation strategies, resulting in a more comprehensive decision-making process. Consequently, the findings of this study not only address risk identification and mitigation but also generate more optimal strategy prioritization based on the relationships among criteria.

By integrating these three methods, PT XYZ is able to systematically map its supply chain activities and pinpoint the most critical risks. The mitigation strategies developed through this approach are anticipated to be more robust, as they account for the interconnections among risk factors, thereby improving both the effectiveness and sustainability of the company's supply chain operations.

METHODS

To obtain data for this research, the study employed field observations, conducted interviews, and organized Focus Group Discussions (FGDs) with stakeholders participating in supply chain processes. The FGD approach was employed to obtain a comprehensive understanding of the actual conditions and to identify risk events and their underlying causes based on the operational experiences of the respondents. This approach ensured that the data collected were contextual and closely aligned with the company's real operational conditions.

The study began by examining the company's supply chain processes using the Supply Chain Operations Reference (SCOR) model, a standard tool for assessing supply chain performance (Gulo et al., 2025). From this mapping, risk events and agents were identified as key areas of focus. The House of Risk (HOR) Phase 1 method was then applied to evaluate risks by analyzing impact severity, probability of occurrence, and the connections between events and their causal agents. These assessments were translated into Aggregate Risk Potential (ARP) values, which were further examined using the 80/20 Pareto Diagram to determine priority risk agents, forming the foundation for mitigation planning (Fitriani & Nugraha, 2022). In HOR Phase 2, the selected agents informed the development of mitigation strategies, which were assessed through the Total Effectiveness of Action (TEk) and Difficulty of Action (Dk). Finally, these metrics were combined into the Effectiveness-to-Difficulty Ratio (ETDk) to pinpoint the most practical and impactful strategies for implementation (Lusiani & Amara, 2023).

Following prioritization in HOR Phase 2, the mitigation strategies were analyzed using the Analytical Network Process (ANP) method, which is designed to handle decision-making problems involving interdependent criteria at the same level (Suhara dkk., 2025). According to Ascarya, as cited in Saputro & Sukmana, (2020), the Analytical Network Process (ANP) has various forms and can be applied in different modeling structures. One of its commonly used models is BOCR (Benefits, Opportunities, Costs, and Risks).

RESULTS AND DISCUSSION

A. Pemetaan Risiko Pada Aktivitas Rantai Pasok Berdasarkan Pendekatan FGD

Through the Focus Group Discussion (FGD) involving representatives from multiple divisions, a detailed mapping of PT XYZ's supply chain processes was achieved. The Supply Chain Operations Reference (SCOR) framework guided the classification of processes, which was then adapted to accurately represent the company's real operational conditions and workflow. According to the SCOR model, supply chain processes fundamentally integrate Plan, Source, Make, Deliver, and Return activities, starting from suppliers to customers (Sholeh dkk., 2020). This mapping serves as the foundation for supply chain risk analysis, enabling the identification of potential issues at each stage of the process that may affect the smoothness of silica sand production and distribution.

Table 1 Risk Mapping in Supply Chain Activities Based on the FGD Approach

SCOR Process	Workstation	Description	Activity Details
Plan	Mining	Silica Sand Raw Material Extraction Process from the Mining Area	At the mining workstation, activities begin with planning the extraction of silica sand raw materials, which includes determining the target excavation volume, arranging the active mining pit areas, and scheduling the use of heavy equipment in accordance with the processing unit's capacity. Subsequently, operational activities are carried out in the form of excavating silica sand material using heavy equipment such as excavators and loaders. The extracted material is then loaded onto transportation fleets to be delivered to the processing unit. This activity functions to ensure the availability of silica sand raw materials as the primary input for the processing operations.
Source	Internal Transportation	Process of Transferring Mining Material to the Processing Unit	Silica sand material from the mining area is transported to the processing unit using trucks with a capacity of 6 cubic meters. The transportation is carried out alternately by taking into account fleet capacity and the travel distance between the mining site and the processing unit. This process involves coordination among truck drivers, mining operators, and field supervisors to ensure that the flow of material delivery proceeds according to the established schedule.
Make	Gedang Goreng Plant	Proses pemisahan	At the Gedang Goreng Plant, silica sand is processed using a dual-rotation system to separate stone fragments and iron

		pasir dari lumpur dan fero	(ferro) content from the sand material. In addition, this unit is equipped with an overflow system designed to remove mud content. Through this process, cleaner silica sand is produced before being transferred to the next processing stage through a pipeline system leading to the Emplog Plant.
	Emplog Plant	Fine Mud Separation and Sand Storage Process	At the Emplog Plant, silica sand is directed into three storage hoppers and one collector hopper. At this stage, a separation process between sand and fine mud is carried out, where the separated sand is subsequently channeled into the collector hopper. The separation process utilizes water within a closed-loop circulation system, allowing the water to be reused. The water flow is regulated by water pumps to maintain the stability and effectiveness of the separation process.
	Kucur Plant	Sand Particle Size Separation Process According to Standards	The Kucur Plant represents the final stage of processing, where silica sand is screened and classified based on particle size using four trommel units. In addition, the screening process utilizes mesh screens to ensure uniformity of sand size. Silica sand that meets the required specifications is subsequently transferred to the storage area.
Deliver	Stockpile Area	Drying and Storage Process of Processed Material	At the storage stage, silica sand is placed in the stockpile area to undergo a natural drying process by utilizing sunlight exposure. Once the silica sand has dried, it is stacked and grouped according to quality or particle size. Each batch is then labeled with proper identification to facilitate the distribution process.
Return	Delivery	Silica Sand Distribution Process to Customers	Silica sand that meets the required quality standards is delivered to customers using truck fleets in accordance with the predetermined schedule and order quantities. The distribution process involves the logistics team in preparing delivery documents, ensuring that the shipment matches the customer's order specifications, recording the departure time of each fleet, and updating stock data in the stockpile area.

Through the Focus Group Discussion (FGD), the study identified key risk events and their corresponding agents, which served as the main input for implementing the House of Risk (HOR) method in developing mitigation strategies. Table 2 provides an overview of these identified risks and agents, forming the essential basis for conducting a comprehensive supply chain risk analysis.

Table 2 Recapitulation of Risk Events and Risk Agents Obtained from the FGD Results as the Basis for Supply Chain Risk Analysis

SCOR	(Ei)	Risk Event	(Ai)	Risk Agent
Plan	E1	Inaccuracy in production planning due to differences between actual excavation volume and target.	A1	Mismatch between RKAB planning data and actual field conditions.
Source	E2	Limited active mining pit openings hinder material extraction.	A2	Delay in opening new mining areas due to limited equipment and operational permits.
	E3	Increasing excavation depth raises transportation time and costs.	A3	The silica sand layer is located deeper underground, requiring longer excavation time.
	E4	Heavy equipment failure (excavator/loader) causes operational stoppages.	A4	Insufficient routine maintenance of heavy equipment (excavator/loader) and delays in spare part replacement.

	E5	Extreme weather disrupts mining operations.	A5	Rescheduling of mining activities during rainfall is not integrated with other divisions, causing disruptions in material supply flow.
	E6	Dependence on subcontractor fleets for internal transportation.	A6	Inconsistent coordination and control of subcontractors in reporting schedules and fleet performance.
	E7	Truck breakdowns cause delays in raw material distribution.	A7	Poor maintenance of subcontractor-owned fleets and lack of direct supervision by PT Andalan Silika over fleet readiness prior to shipment.
	E8	Uneven or slippery mining roads hinder fleet mobility.	A8	Road maintenance frequency is not fully aligned with the intensity of transportation activities, leading to faster road deterioration during peak operations.
Make	E9	Rotation machine failure disrupts the material separation process.	A9	Machine performance declines due to prolonged operating hours and delayed maintenance.
	E10	Blockage in the overflow system disrupts sand flow.	A10	Accumulation of fine particles that are not routinely cleaned due to tight operational schedules.
	E11	High iron (ferro) content remains after the separation process.	A11	Decreased efficiency of the magnetic separator due to improper calibration and variations in raw material characteristics.
	E12	Instability in material flow due to differences in machine rotation speed.	A12	Unstable synchronization among rotation machines due to differences in technical load of the equipment.
	E13	Overload in the collector hopper causes material accumulation.	A13	Imbalance between input rate and hopper capacity due to differences in flow rates between plants.
	E14	Water pump failure causes the circulation process to stop.	A14	Component wear and suboptimal implementation of preventive maintenance, leading to reduced circulation system performance.
	E15	Trommel damage disrupts the screening process.	A15	Lack of regular inspection of the trommel, resulting in damage being detected only after process disruption occurs.
	E16	Sand particle size does not meet customer standards.	A16	Improper mesh screen adjustment due to variations in input pressure and screen wear.
	E17	Decrease in SiO_2 content after the final process.	A17	Material mixing between batches in the stockpile area, affecting the final SiO_2 content.
Deliver	E18	Stock accumulation due to delayed shipments.	A18	Imbalance between production capacity and subcontractor transportation capacity.
	E19	Contamination between different sand quality grades during stockpiling.	A19	The storage area does not yet have a permanent partition system for each product grade.
	E20	Errors in stock labeling cause inaccurate deliveries.	A20	The labeling process is still performed manually, increasing the potential for input errors.
	E21	Delivery delays due to subcontractor fleet issues.	A21	Delays in subcontractor fleet deployment for several shipments.
	E22	Cargo damage during transportation.	A22	Damage to cargo caused by suboptimal truck covering methods or poor weather

				conditions, resulting in partial exposure and quality degradation.
Return	E23	Customer complaints due to non-conforming products.	A23	Differences in documentation systems between PT Andalan Silika Tuban and subcontractors, leading to discrepancies in delivery documents.

B. House of Risk (HOR) Method

Focusing on preventive measures, the House of Risk (HOR) model identifies critical risk events that need mitigation or management (Defriyanti & Ernawati, 2021). Comprising two phases HOR Phase 1 and HOR Phase 2 each phase emphasizes a different analytical objective. During Phase 1, the prioritization of risk sources is carried out by evaluating the impact severity, frequency of occurrence, and the relationships between each risk event and its causal agents, with the results subsequently converted into Aggregate Risk Potential (ARP) values. Phase 2, on the other hand, provides recommended mitigation actions based on the prioritized risks (Maharani et al., 2022). The ARP calculations and corresponding rankings for each risk agent are summarized in Table 3.

Table 3 Ranking of Aggregate Risk Potential (ARP)

Rank	Ai	Risk Agent	ARP
1	A3	The silica sand layer is located deeper underground, requiring longer excavation time.	1053
2	A15	Lack of regular inspection of the trommel, resulting in damage being detected only after process disruption occurs.	936
3	A1	Mismatch between RKAB planning data and actual field conditions.	855
4	A9	Machine performance declines due to prolonged operating hours and delayed maintenance.	693
5	A14	Component wear and suboptimal implementation of preventive maintenance, leading to reduced circulation system performance.	672
6	A5	Rescheduling of mining activities during rainfall is not integrated with other divisions, causing disruptions in material supply flow.	623
7	A7	Poor maintenance of subcontractor-owned fleets and lack of direct supervision by PT Andalan Silika over fleet readiness prior to shipment.	616
8	A4	Insufficient routine maintenance of heavy equipment (excavator/loader) and delays in spare part replacement.	567
9	A2	Delay in opening new mining areas due to limited equipment and operational permits.	558
10	A21	Delays in subcontractor fleet deployment for several shipments.	468
11	A12	Unstable synchronization among rotation machines due to differences in technical load of the equipment.	435
12	A10	Accumulation of fine particles that are not routinely cleaned due to tight operational schedules.	420
13	A18	Imbalance between production capacity and subcontractor transportation capacity.	420
14	A16	Improper mesh screen adjustment due to variations in input pressure and screen wear.	360
15	A23	Differences in documentation systems between PT Andalan Silika Tuban and subcontractors, leading to discrepancies in delivery documents.	360
16	A11	Decreased efficiency of the magnetic separator due to improper calibration and variations in raw material characteristics.	315

17	A17	Material mixing between batches in the stockpile area, affecting the final SiO_2 content.	312
18	A6	Inconsistent coordination and control of subcontractors in reporting schedules and fleet performance.	306
19	A8	Road maintenance frequency is not fully aligned with the intensity of transportation activities, leading to faster road deterioration during peak operations.	261
20	A13	Imbalance between input rate and hopper capacity due to differences in flow rates between plants.	252
21	A22	Damage to cargo caused by suboptimal truck covering methods or poor weather conditions, resulting in partial exposure and quality degradation.	252
22	A19	The storage area does not yet have a permanent partition system for each product grade.	186
23	A20	The labeling process is still performed manually, increasing the potential for input errors.	156

$$ARP_j = O_j \sum S_i R_{ij}$$
$$ARP_{A3} = O_{A3} \times ((S_{E1} \times 3) + (S_{E2} \times 3) + (S_{E3} \times 9)$$
$$ARP_{A3} = 9 \times \left((7 \times 3) + (8 \times 3) + (8 \times 9)\right)$$
$$ARP_{A3} = 1053$$

Once the Aggregate Risk Potential (ARP) values were calculated, the risk agents were ranked according to their level of contribution using the Pareto Diagram approach to identify the most significant ones. Risk agents with a cumulative percentage of 0–80% were designated as priorities for mitigation strategy development in accordance with the Pareto 80/20 principle (Fitriani & Nugraha, 2022).

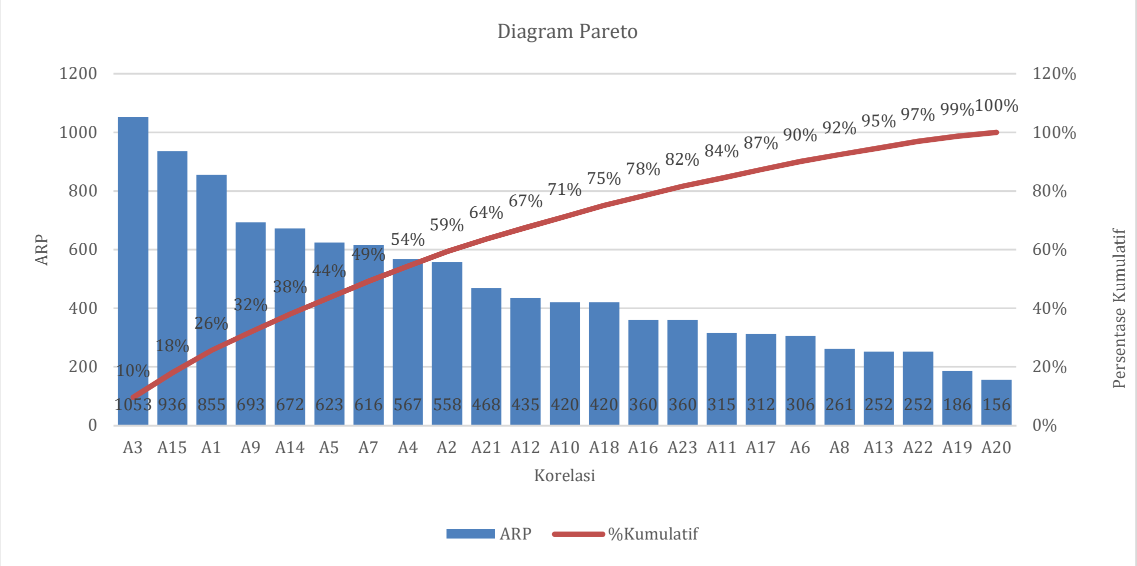


Figure 1 Pareto Diagram

Following the ranking process, the risk agents selected for mitigation were identified, totaling 14 agents with the highest ARP values, which together amounted to 8,676 or 78% of the overall ARP of all risk agents. The company confirmed that these agents have a significant impact and could potentially disrupt supply chain operations at PT XYZ. These prioritized risk agents then served as the basis for developing mitigation strategies in HOR Phase 2. The recommended mitigation actions, labeled as PA, are summarized in Table 4.

Table 4 Mitigation Action Strategies

Risk Agent		Proposed Mitigation Action Strategies	
A3	The silica sand layer is located deeper underground, requiring longer excavation time.	PA1	Optimize hauling routes and adjust hauling schedules based on excavation depth.
A15	Lack of regular inspection of the trommel, resulting in damage being detected only after process disruption occurs.	PA2	Develop a trommel inspection checklist covering screen condition, bearings, and trommel rotation, to be conducted periodically and documented.
A1	Mismatch between RKAB planning data and actual field conditions.	PA3	Conduct quarterly technical reviews of the RKAB based on production realization data and field conditions.
A9	Machine performance declines due to prolonged operating hours and delayed maintenance.	PA4	Arrange alternating production machine schedules to avoid excessive machine usage within a single operational period.
A14	Component wear and suboptimal implementation of preventive maintenance, leading to reduced circulation system performance.	PA5	Implement preventive maintenance for water pumps based on operating hours by establishing service life limits for critical components.
A5	Rescheduling of mining activities during rainfall is not integrated with other divisions, causing disruptions in material supply flow.	PA6	Develop alternative mining activity schedules during periods of high rainfall.
A7	Poor maintenance of subcontractor-owned fleets and lack of direct supervision by PT Andalan Silika over fleet readiness prior to shipment.	PA7	Assign a dedicated supervisor to ensure subcontractor fleet readiness prior to shipment.
A4	Insufficient routine maintenance of heavy equipment (excavator/loader) and delays in spare part replacement.	PA8	Provide critical spare parts to accelerate repair processes.
A2	Delay in opening new mining areas due to limited equipment and operational permits.	PA9	Implement early operational readiness control by ensuring the availability of operational equipment and permits before the scheduled opening of new mining areas to prevent initial operational delays.
A21	Delays in subcontractor fleet deployment for several shipments.	PA10	Establish multi-vendor contracts for transportation fleets.
A12	Unstable synchronization among rotation machines due to differences in technical load of the equipment.	PA11	Conduct routine calibration of rotation machines and adjust machine workload according to equipment age and technical condition.
A10	Accumulation of fine particles that are not routinely cleaned due to tight operational schedules.	PA12	Schedule routine cleaning of fine particles at sediment-prone points.
A18	Imbalance between production capacity and subcontractor transportation capacity.	PA13	Align daily production plans with subcontractor fleet capacity through regular coordination meetings.
A16	Improper mesh screen adjustment due to variations in input pressure and screen wear.	PA14	Establish technical standards for mesh screen usage according to product specifications and conduct inspections of mesh condition prior to the screening process.

Once the mitigation action strategies were developed, HOR Phase 2 proceeded with evaluating the correlation between each strategy and its associated risk agents to verify their relevance. These correlations were measured using a Likert scale. To calculate the Total

Effectiveness of Action (TEk) for each strategy, the ARP value of the relevant risk agent was multiplied by its corresponding correlation coefficient. Following this, the Difficulty of Performing Action (Dk) was assessed to reflect the challenges in implementing each mitigation strategy. The TEk and Dk values were subsequently combined to compute the Effectiveness-to-Difficulty Ratio (ETDk), indicating the balance between a strategy's effectiveness and implementation difficulty. Based on ETDk results, the mitigation actions were ranked from highest to lowest priority. Table 5 provides a summary of the evaluation outcomes for these mitigation actions.

Table 5 Recapitulation of Mitigation Action Evaluation Results

Rank	PA	Mitigation Strategy	Tek	Dk	ETDk
1	PA9	Implement early operational readiness control by ensuring the availability of operational equipment and permits before the scheduled opening of new mining areas to prevent initial operational delays.	10746	3	3582
2	PA3	Conduct quarterly technical reviews of the RKAB based on production realization data and field conditions.	9789	3	3263
3	PA1	Optimize hauling routes and adjust hauling schedules based on excavation depth.	11766	4	2942
4	PA2	Develop a trommel inspection checklist covering screen condition, bearings, and trommel rotation, to be conducted periodically and documented.	10422	4	2606
5	PA6	Develop alternative mining activity schedules during periods of high rainfall.	9621	4	2405
6	PA4	Arrange alternating production machine schedules to avoid excessive machine usage within a single operational period.	9243	4	2311
7	PA11	Conduct routine calibration of rotation machines and adjust machine workload according to equipment age and technical condition.	6930	3	2310
8	PA13	Align daily production plans with subcontractor fleet capacity through regular coordination meetings.	6345	3	2115
9	PA8	Provide critical spare parts to accelerate repair processes.	8175	4	2044
10	PA5	Implement preventive maintenance for water pumps based on operating hours by establishing service life limits for critical components.	6048	3	2016
11	PA12	Schedule routine cleaning of fine particles at sediment-prone points.	4452	3	1484
12	PA7	Assign a dedicated supervisor to ensure subcontractor fleet readiness prior to shipment.	5544	4	1386
13	PA14	Establish technical standards for mesh screen usage according to product specifications and conduct inspections of mesh condition prior to the screening process.	3240	3	1080
14	PA10	Establish multi-vendor contracts for transportation fleets.	4212	4	1053

The following is an example of the manual calculation of the Effectiveness to Difficulty Ratio (ETDk) for PA1:

$$\mathrm{ETDk}_1 = \frac{\mathrm{TPA1}}{\mathrm{D1}}$$

$$\mathrm{ETDk}_1 = \frac{11766}{4}$$

$$\mathrm{ETDk}_1 = 2942$$

C. Analytical Network Process (ANP) Method

During the application of the Analytical Network Process (ANP) method, model development starts by establishing the primary research objective. For this study, the objective is defined as identifying the most suitable priority risk mitigation strategy for implementation at PT

XYZ, based on the Benefit, Opportunity, Cost, and Risk (BOCR) criteria. The establishment of this goal ensures that the prioritized mitigation strategy is not only effective in controlling risks but also feasible from the company's perspective. After defining the objective, the next step is to determine the criteria used as the basis for evaluating decision alternatives. The criteria in the ANP model are structured using the Benefit, Opportunity, Cost, and Risk (BOCR) approach. The use of BOCR criteria is considered capable of providing a comprehensive assessment of risk mitigation strategies, as also applied in previous research by Dewi dkk., (2025). Furthermore, the alternatives considered in this study consist of the risk mitigation strategies generated from House of Risk (HOR) Phase 2.

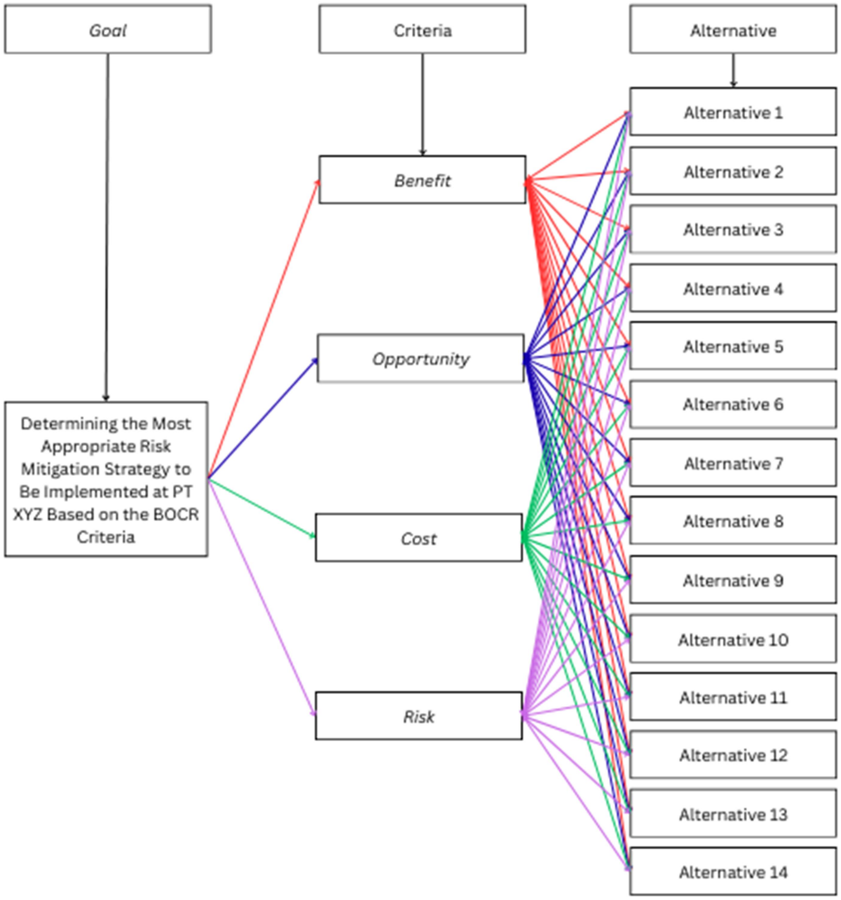


Figure 2 ANP Hierarchical Structure

1. Consistency Ratio

At this stage, the consistency level of respondents' judgments was also examined by calculating the Consistency Ratio (CR). The assessment data are considered acceptable if the obtained CR value does not exceed 0.1. Conversely, if the CR value is greater than 0.1, the respondents' judgments are deemed inconsistent and require reconsideration before being used in the decision-making process (Qomariyah dkk., 2024). Based on the consistency ratio calculations, all pairwise comparison matrices resulted in CR values ≤ 0.1, indicating that the respondents' judgments were consistent and suitable for further ANP analysis. Table 6 presents the recapitulation of the consistency ratios generated using the Super Decisions software.

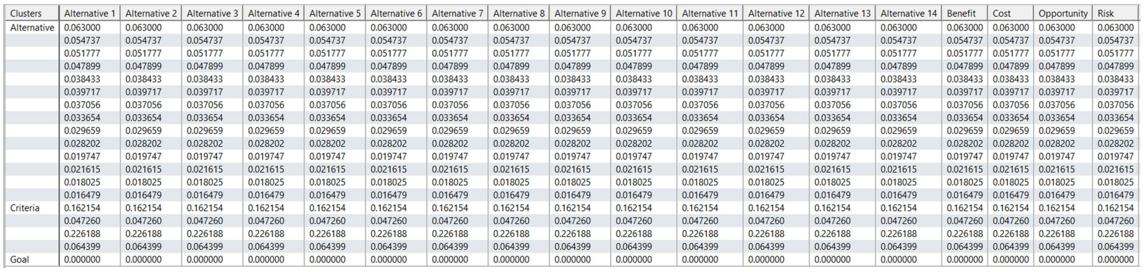
Table 6 Recapitulation of Consistency Ratio

	Rasio Konsistensi
Goal→Criteria	0,05221
Benefit→Alternative	0,04264
Opportunity→ Alternative	0,01885
Cost→ Alternative	0,04731
Risk→ Alternative	0,04604
Alternative 1→ Criteria	0,06656
Alternative 2→ Criteria	0,09088
Alternative 3→ Criteria	0,09636
Alternative 4→ Criteria	0,03626
Alternative 5→ Criteria	0,05770
Alternative 6→ Criteria	0,06271
Alternative 7→ Criteria	0,04923
Alternative 8→ Criteria	0,08062
Alternative 9→ Criteria	0,07889
Alternative 10→ Criteria	0,06827
Alternative 11→ Criteria	0,08881
Alternative 12→ Criteria	0,08916
Alternative 13→ Criteria	0,09088
Alternative 14→ Criteria	0,09888

2. Supermatrix Determination

In the Analytical Network Process (ANP) method, the calculation process is carried out using a complex matrix structure known as the Supermatrix. Within the Supermatrix framework, the Limit Supermatrix represents the final result derived from the Weighted Supermatrix, where the weights are further stabilized using the overall eigenvector values of the clusters (Dewi dkk., 2025). Table 7 presents the Limit Supermatrix obtained from the analysis conducted using the Super Decisions software.

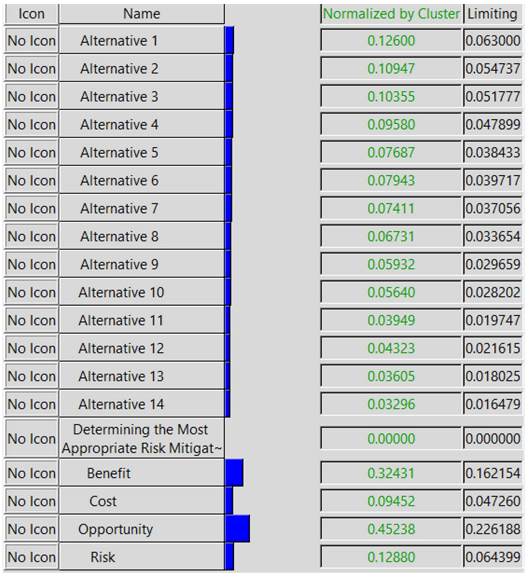
Table 7 Limit Supermatrix



Clusters	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10	Alternative 11	Alternative 12	Alternative 13	Alternative 14	Benefit	Cost	Opportunity	Risk
Alternative	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000	0.063000
	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737	0.054737
	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777	0.051777
	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899	0.047899
	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433	0.038433
	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717	0.039717
	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056	0.037056
	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654	0.033654
	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659	0.029659
	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202	0.028202
	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747	0.019747
	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615	0.021615
	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025	0.018025
	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479	0.016479
Criteria	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154	0.162154
	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260	0.047260
	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188	0.226188
	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399	0.064399
Goal	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Based on Table 7 above, the identical values in each column of the Limit Supermatrix indicate that the convergence process has been achieved. The weights in the alternative rows represent the final priorities of the risk mitigation strategies, where Alternative 1 has the highest weight of 0.063117 and is therefore ranked as the top priority, followed by Alternative 2 with a weight of 0.055200 and Alternative 3 with 0.052003. In contrast, the lowest weight is assigned to Alternative 14 at 0.016549. Meanwhile, the criterion weights show that Opportunity 0.221000 and Benefit 0.162131 have a more dominant influence compared to Risk 0.067060 and Cost 0.049809. This indicates that the decision-making process emphasizes long-term opportunities and benefits more strongly than cost and risk considerations.

3. Priority Weighting and Ranking



Icon	Name	Normalized by Cluster	Limiting
No Icon	Alternative 1	0.12600	0.063000
No Icon	Alternative 2	0.10947	0.054737
No Icon	Alternative 3	0.10355	0.051777
No Icon	Alternative 4	0.09580	0.047899
No Icon	Alternative 5	0.07687	0.038433
No Icon	Alternative 6	0.07943	0.039717
No Icon	Alternative 7	0.07411	0.037056
No Icon	Alternative 8	0.06731	0.033654
No Icon	Alternative 9	0.05932	0.029659
No Icon	Alternative 10	0.05640	0.028202
No Icon	Alternative 11	0.03949	0.019747
No Icon	Alternative 12	0.04323	0.021615
No Icon	Alternative 13	0.03605	0.018025
No Icon	Alternative 14	0.03296	0.016479
No Icon	Determining the Most Appropriate Risk Mitigat~	0.00000	0.000000
No Icon	Benefit	0.32431	0.162154
No Icon	Cost	0.09452	0.047260
No Icon	Opportunity	0.45238	0.226188
No Icon	Risk	0.12880	0.064399

Figure 3 Priority Results

The priority results shown in Figure X represent the final outcome of determining the risk mitigation strategy alternatives using the Super Decisions software with the Analytical Network Process (ANP) method. Based on the *normalized by cluster* values of the mitigation strategy alternatives, Alternative 1 obtained a value of 0.12623, followed by Alternative 2 with 0.11040 and Alternative 3 with 0.10401. These results indicate that Alternative 1 has the highest relative importance within the alternative cluster. Meanwhile, the lowest *normalized by cluster* value is held by Alternative 14, with a value of 0.03310. In terms of the criteria, the *normalized by cluster* values show that Opportunity has the highest weight at 0.44200, followed by Benefit at 0.32426, Risk at 0.13412, and Cost at 0.09962. This indicates that, in determining the risk mitigation strategy, Opportunity and Benefit serve as the primary considerations compared to the other criteria.

D. Rater Agreement Calculation

Rater Agreement analysis is a measure used to determine the level of consistency or agreement among respondents (R1–Rn) in assessing a particular issue within a cluster. The measurement of rater agreement is conducted using Kendall's Coefficient of Concordance (W), which ranges from $0 < W < 1$. A W value closer to 1 indicates a high level of agreement among respondents, whereas a W value closer to 0 reflects greater variation or differences in judgments (Dewi dkk., 2025).

	U	S	MaxS	W
Alternative	37,5	5589,5	5687,5	0, 9827692
Criteria	12,5	117	125	0,936

Based on the results of the Rater Agreement calculation in Table X, the Kendall's Coefficient of Concordance (W) value obtained was 0.98276923 for the alternatives and 0.936 for the criteria. Since both values fall between 0 and 1 and are near the maximum, respondents showed strong consensus in their evaluations of the risk mitigation alternatives and the applied criteria. This high level of agreement demonstrates that the assessments are consistent and dependable, making the analysis results a reliable foundation for decision-making. This high level of agreement demonstrates that the assessments are consistent and dependable, making the analysis results a reliable foundation for decision-making. According to Martono et al., (2022), a Kendall's Coefficient of Concordance (W) value approaching 1 indicates a strong level of agreement among raters, confirming the reliability of the evaluation results.

CONCLUSION

Through Focus Group Discussions (FGD) and direct observation of supply chain activities, the study at PT XYZ identified 23 risk events and 23 associated risk agents. Using HOR Phase 1 in combination with the 80/20 Pareto principle, 14 of the most critical risk agents were selected to form the basis for designing mitigation strategies. In HOR Phase 2, these strategies were evaluated using the Effectiveness-to-Difficulty Ratio (ETDk) to determine their priority and feasibility. The results show that PA9 obtained the highest ETDk value of 3582, followed by PA3 with 3263 and PA1 with 2942. PA9 focuses on ensuring early operational readiness through the completeness of equipment and permits before the opening of mining areas. PA3 emphasizes quarterly technical reviews of the RKAB based on production realization and field conditions, while PA1 involves optimizing hauling routes and adjusting hauling schedules according to excavation depth. Further evaluation using the Analytical Network Process (ANP) with BOCR criteria confirmed PA9 (Alternative 1) as the top priority with a weight of 0.12623, followed by PA3 (0.11040) and PA1 (0.10401). The Rater Agreement test yielded W values of 0.98276923 for alternatives and 0.936 for criteria, indicating very high respondent agreement and consistent results. Overall, production gaps and fluctuations are mainly influenced by delays in initial operations and insufficient mining readiness. The priority strategy PA9 directly addresses this root cause, while PA3 and PA1 support improvements in planning alignment and operational efficiency.

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