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Integration of House of Risk and Analytic Network Process Methods in Mitigation of Risk in the Sugar Production Process

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Abstract

PT.XYZ is a company engaged in manufacturing, specifically in the production of granulated sugar. The problem that occurs in this company is the increasing number of gravel sugar defects by 18% or 1,019.52 tons. This number far exceeds the defect limit set by the company of 5% or 283.2 tons per month. Therefore, the purpose of this study is to identify the risks of the sugar production process using the House of Risk (HOR) method and determine the best alternative for priority risk mitigation through the Analytic Network Process (ANP) method at PT.XYZ. The HOR method is used to identify and classify risks based on severity and likelihood. Furthermore, the ANP method is used to determine the priority of risk mitigation strategies by considering the interdependence between risks. The results of the study showed that through the Focus Group Discussion (FGD) approach, 25 risk events and 25 risk sources were obtained which will be used to determine the mitigation strategy in the House Of Risk (HOR) method. Based on the calculation results of the rate agreement for alternative (W) of 0.777778, it shows a fairly high level of conformity among respondents' answers in selecting risk mitigation alternatives. Based on the calculation results on the super decision software, the highest normalized value was obtained, namely in the Desuperheater alternative of 0.51145. With this research, it is expected to help companies in overcoming company problems and can increase profits for the company.

Introduction

In the manufacturing industry, the process of processing raw materials into finished goods is certainly not free from potential risks or can be called the nature of uncertainty. In research conducted by Gunawan et al. (2021), stating that the risk or nature of uncertainty will cause an impact that can be detrimental and can result in the failure to achieve the company's goals. In addition, competition in the increasingly tight business world requires companies to survive in order to continue to provide products with the best quality and service (Riadi et al., 2021). For that reason, companies need to be aware of the importance of risks or disruptions that can affect business continuity. The company's efforts to maintain business processes can be implemented through risk management in the supply chain, especially in production activities. Through this, the continuity of the supply chain can be maintained and can increase the company's profits (Prasetyo et al., 2022; Syed et al., 2024; Lin et al., 2022; Egila et al., 2025; Rauniyar et al., 2023; Ishak et al., 2023).

PT. XYZ is a company engaged in sugar production located in East Java. The existence of PT. XYZ is not only to produce sugar, but also has an important contribution to the local and

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national economy, especially in the agricultural and food industry sectors. For this reason, PT. XYZ must be able to optimize the production process to create high-quality products that can meet consumer needs. The problem faced by PT. XYZ in June 2024 was the increasing number of gravel sugar defects by 18% or 1,019.52 tons. This number far exceeds the defect limit set by the company of 5% or 283.2 tons each month. Gravel sugar, which is a defective product, requires remelting at a cooking workstation with a cooking pan capacity of 5,664 tons. This process extends production time and reduces productivity because additional energy and resources must be used. In addition, the large number of defects has a direct impact on the supply chain flow, causing an imbalance between demand and supply. As a result, the company was only able to supply 3,489.38 tons of white crystal sugar in June, which can be seen in table 1 in tons.

Table 1. Data on Demand and Amount of Sugar Produced in 2024

Period	Total Requests	Total Sugar Production	Number of Defects	Defect percentage
05/29/2024 -05/31/2024	35.00	35.00	11.6	0.03%
01/06/2024- 30/06/ 2024	4,580.90	3,489.38	1091.52	18%
01/07/2024 - 31/07/2024	4,072.40	5,163.92	271,872	4.8%
01/08/2024 - 31/08/2024	3,491.30	3,491.30	192,576	3.40%
01/09/2024 - 11/09/2024	1,277.00	1,277.00	164,256	2.90%
Total	13,456.60	13,456.60	1731,824	5.83%

Based on the problemthe,PT. XYZ needs to doto identify risk sources and appropriate risk mitigation priorities to address risks that cause an increase in the number of gravel sugar defects. In previous researchconducted by Hadi et al. (2020)stated that the House of Risk method only focuses on risk identification and assessment without considering the company's capacity and resources to implement the proposed mitigation measures. In this study, the integration of the Analytical Network Process (ANP) method aims to improve the House of Risk (HOR) method, namely by modeling the relationship between criteria and alternatives that can be adjusted to needs. Through the Analytical Network Process (ANP) method, it can provide the best alternative through weighting with the freedom to compile models according to needs into a complex network form (Natalia et al., 2020; Khanmohammadi et al., 2024; Schulze-González et al., 2021; Wijayanti et al., 2022; Dewi et al., 2025).

This research is expected to provide a significant contribution to PT. XYZ in dealing with supply chain constraints, especially related to the risk of increasing defects that hinder the sugar production process. Through an in-depth analysis of each work station starting from the milling station, refining station, evaporation station, cooking station, Turning station to production support station (boiler). This research is expected to be able to produce the best alternative that can be implemented directly for the company, so that it can maintain the flow of the supply chain and improve overall operational efficiency.

Focus Group Discussion (FGD)

FGD is a process of collecting information about a very specific problem through group discussions. FGD can be defined as a method and technique in collecting qualitative data where a group of people discuss a particular problem or topic (Kurniadi et al., 2023; Yayeh, 2021; Susanto et al., 2024; Lanshima & Abdulkarim, 2021; Khan & Abedin, 2022). The main objective of the FGD method is to obtain data interaction resulting from a discussion of a group of participants/respondents in terms of increasing the depth of information revealing various aspects of a life phenomenon, so that the phenomenon can be defined and explained. Data from the results of interactions in the group discussion can focus or emphasize similarities and differences in experience and provide solid information/data about a perspective resulting from the results of the group discussion (Indrizal, 2019).

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House of Risk(HOR)

The House of Quality (QFD) and Failure Modes and Effects Analysis (FMEA) techniques are developed using the House of Risk (HOR) concept (Pujawan, 2009; Meilina, 2024; Herdiani et al., 2021). Prioritising which risk agents require attention first is done using HOQ, while risk assessment is done using FMEA. According to Dewi et al. (2025), the House of Risk (HOR) is a needs-based risk management approach that focusses on each preventative action to determine which risk event is the dominant risk. Action will then be taken to reduce or manage the risk. There are two stages to the House of Risk method: HOR stage 1 and HOR stage 2. The focus of HOR Stage 1 on identifying the risk sources that need to be given priority for mitigation measures is where the two stages diverge (Aldi Rizki, 2022). Meanwhile, HOR Phase 2 is intended to provide recommendations for preventive measures as a follow-up to the risks that have been prioritized (Maharani, 2022).

Analytic Network Process(ANP)

The Analytical Hierarchy Process (AHP) approach was developed into the Analytic Network Process (ANP). The capacity to account for the link between criteria or alternatives is one way that the ANP approach can strengthen the shortcomings of the AHP. Composite priority ratios are derived from separate ratio scales that represent relative assessments of the influence of interacting elements with respect to control requirements using the ANP, a broad theory of relative measurement. ANP is a mathematical framework that enables systematic dependence and feedback analysis, capturing and integrating both tangible and intangible elements (Anissa, 2020; Chang et al., 2023; Masudin et al., 2024). ANP is a general theory of measurement in essence. Ratio scales can be found using ANP in both discrete and continuous pair comparisons (Natalia et al., 2020; Jorge-García & Estruch-Guitart, 2022).

Geometric Mean

The geometric mean calculation is used for research that uses questionnaires to determine their weight. The questionnaires that have been collected are arranged to provide weighting for the criteria that have been determined by comparing one criterion with another criterion on a scale of 1 to 9. The data obtained from respondents are checked for their consistency index, if they are inconsistent (the consistency index is <0.10), then the questionnaire must be repeated. After the power is collected before the calculation is carried out using the DSS method, a calculation is first carried out using the geometric mean (Geometric Mean) where this calculation is to provide a better average approach because it can eliminate the deviations that occur for the data obtained from the respondents' assessments in the questionnaire (Yosritzal et al., 2019; Puška et al., 2022; Kusmaryono et al., 2022).

Rate Agreement

Rater agreement analysis is a measure that shows the level of suitability (agreement) of respondents (R1-Rn) to a problem in one cluster. The tool used to measure rater agreement is Kendall's coefficient of concordance (W; $0 < W < 1$). If the test value $W = 1$, it can be concluded that the assessment or opinion of the respondents has perfect conformity, conversely if the value $W = 0$ or is getting closer to 0, it indicates a discrepancy between the respondents' answers or varying answers (Pratiwi et al., 2021). By calculating rater agreement, researchers can ensure that the data obtained from questionnaires or interviews have a fairly high level of agreement, so that the results of the ANP analysis are more valid and reliable (Fatikhah et al., 2020).

Software Super Decision

Super Decisions is a decision-making software that works based on two multi-criteria decision-making methods. Super Decisions implements the Analytical Hierarchy Process and

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the Analytical Network Process. Super Decision software can complete the ANP matrix computation process. The advantage of this software is its high level of accuracy compared to conventional programs such as Microsoft Excel (Jeprimansyah & Husna, 2019).

Methods

An interlinked method between the House of Risk (HOR) approach and Analytic Network Process (ANP) enables evaluation and prioritization of risk mitigation strategies in the production sequence at PT. XYZ. A Focus Group Discussion (FGD) enables expert participants to share their knowledge about potential risks as well as the root causes impacting different production workstations during the initial qualitative data collection stage. Kurniadi et al. (2023) indicates researcher can obtain intricate and context-based information from production operation individuals during FGDs to build an extensive risk map.

The initial phase of House of Risk method starts after risk identification takes place. The model bases its risk handling strategies on Supply Chain Risk Management principles through agent source prioritization (Wibowo & Ahyudanari, 2020). Amara (2023) explains that risk severity and occurrences receive scores between 1 to 10 but agents are evaluated for their relationship with risk events using a qualitative ranking system of 0, 1, 3, or 9. Agents receive their Aggregate Risk Potential score through multiplying identified risk values to show their production process impact measurement capacity. The HOR method adopts its principles from Pujawan (2009) who created this method by combining House of Quality (QFD) with Failure Modes and Effects Analysis (FMEA).

Risk agents are evaluated for priority ranking following the Pareto principle so the production issues can be identified from the highest to lowest contributors that cause the excessive number of gravel sugar defects. Research confirms that problems stem from 20% of possible factors which account for 80% of all incidents (Fitriani & Nugraha, 2022). The chosen risk agents from the HOR stage 1 evaluation proceed to HOR stage 2 for creating specific mitigation plans. The effectiveness assessment for each mitigation strategy considers its risk reduction potential (Total Effectiveness, TEk) together with execution difficulty (Dk) according to the procedure presented by Natalia et al. (2020). The calculation of ETDk ratio using two values combines an evaluation of potential impact with feasibility assessment to determine the optimal balance.

The Analytic Network Process (ANP) utilizes the selected mitigation strategy with the highest ETDk value as the objective for its next phase of analysis. Ethical Total Effectiveness (ETDk) benefits from Analytic Network Process (ANP) since it operates on dependent criteria and alternatives. ANP surpasses AHP because it enables the modeling of interdependent and interconnected structures between and within decision levels (Anissa et al., 2020). The ANP model of this study consists of three distinct clusters involving risk mitigation as the goal and decision elements and alternative strategies serving as its components. Benefits and Opportunities along with Costs and Risks (BOCR) stand as the chosen evaluation framework because they deliver a balanced framework according to Fatikhah et al (2020).

The study supports the ANP calculation by obtaining expert questionnaire responses that feature pairwise comparison input. The geometric mean method applies to average all provided comparisons to achieve both consistency and accuracy in the assessment. The geometric mean stands as a strong method for this situation since it mitigates erratic values and inconsistent forecasts (Yosriztal et al., 2019). The values are input into Super Decisions software for execution of complex matrix calculations leading to the creation of unweighted, weighted and limiting super matrices before determining alternative priority rankings.

The process reliability is assessed through Kendall's coefficient of concordance (W) that determines how well multiple judges agree with one another. The W value reveals consensus

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power by approaching one for robust group agreement but signals agreement weak points when nearing zero (Pratiwi et al., 2021). The evaluation of pairwise comparison data consistency depends on this measure to establish ANP result credibility.

Results and Discussion

Mapping of production activities based on the FGD approach

In this studyThis FGD approach is carried out to map production activities to obtain information related to risks at each work station (grinding, refining, evaporation, cooking, Turning and Boiler stations). In this study, the FGD approach was carried out through discussions to extract information from a group of divisions that understand the topic/activity in order to obtain complex information (Kurniadi et al., 2023). This approach is carried out to obtain information related to the current condition of the Company's production process by involving experts, operators, and managers. The results of the FGD approach include risk events and risk causes that will be used as data in the calculation of the HOR method to provide risk mitigation in dealing with the problem of increasing gravel sugar defects that hinder the balance between supply and demand.

Table 2. Risk Event and Risk Agent

(Ei)	Risk Event	(Ai)	Risk Agent
E1	Delay in raw materials	A1	Delay in delivery of raw materials from suppliers
E2	The quality of raw materials does not meet standards	A2	Sugarcane sucrose (pol) levels are low, causing sugar product revenues to fall short of expectations
E3	Cane carrier chain breaks during sugarcane transfer	A3	Overload or burnout of the chain drive motor
E4	A lot of sucrose is lost along with the bagasse during the milling process.	A4	The process of providing imbibition water (water to dissolve sugar content) which is not in accordance with SOP
E5	The sap produced still contains a lot of dirt or solid particles.	A5	The performance of the rotary vacuum filter tool for filtering sap from dirt is not yet optimal
E6	The quality of the sap which is too thin makes the absorption process difficult the sap that has not settled.	A6	Excessive addition of lime milk to the defecation process
E7	The narrowing of the pipe due to sulfitation inhibits the flow of sap.	A7	Pipe crust on sulfation is too thick
E8	The occurrence of coloring in product sugar	A8	An imperfect carbonation process can leave residues that cause color in the product's sugar.
E9	Inhibition of the chemical reaction process between substances in the sap, such as the reaction between lime milk and organic acids in sugar refining.	A9	Preheater temperature not in accordance with SOP
E10	The evaporator heat transfer process is hampered so that the sap temperature does not reach the optimal level for thickening the sap.	A10	The crust condition on the evaporator body is too thick, thus inhibiting the heat transfer process.

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E11	Loose or loose pipe connections causing leaks.	A11	Pressure changes that occur in vacuum pipes continuously
E12	The boiling point of the solution is low so that the Brix (Sap Concentration) does not reach 60-80°	A12	The exhaust steam pressure decreases so that it is unable to optimize the evaporation process.
E13	Sucrose caramelization occurs, which damages the taste and color of the sucrose.	A13	The temperature is too high and the time is too long during the palm sap cooking process.
E14	The occurrence of shocks in the crystallization process	A14	Unstable vacuum pressure on the vacuum pan
E15	BJB (large grain type) uneven sugar crystals	A15	Inconsistent heating process when the sugar solution is concentrated
E16	Incomplete na-crystallization process (advanced crystallization)	A16	Thick sap content with low sugar content (HK) (< 82%)
E17	Sugar crystal seeds are destroyed during the crystallization process.	A17	Cooking temperature that is too high
E18	Damage to rotating tools, especially bearings	A18	The motor that drives the rotary tool often burns out
E19	Sugar crystals come out with the solution (stroop) during the spinning process in low grade fugal	A19	The crystal filter tool often tears in low grade fugal so that the sugar comes out with the solution.
E20	The quality of the sugar product cooking is less than optimal so that the filtered sugar crystals stick to the cylinder walls.	A20	In high grade fugal, sugar products have a high water content.
E21	The occurrence of movement in the boiler pipes causes the flow of heat from the combustion gas to the boiler feed water to be obstructed.	A21	High mineral content in APK (boiler water) forms deposits
E22	Leakage in the boiler steam pipe connection resulting in a decrease in steam pressure.	A22	Boiler gasket installation that is not tightly closed
E23	The heat generated from burning the dregs is less than optimal	A23	The fuel (dregs) used to produce heat has a high water content
E24	Pipe corrosion occurs in the boiler pipe, causing thinning of the pipe material.	A24	APK (boiler feed water) that is too acidic causes corrosion in the pipes
E25	The boiler body bulged and caused an explosion.	A25	APK (boiler feed water) contaminated with sugar so that the sugar sticks to the surface of the boiler and causes the steam pressure in the boiler to not be distributed properly.

House of Risk (HOR) Method

After conducting the FGD approach, the next stage is to calculate the House of Risk (HOR) method. The House of Risk (HOR) method is a model based on Supply Chain Risk Management (SCRM) which focuses on preventive measures to reduce the causes of risk (risk agents) so that it can prevent a risk (risk event) (Wibowo & Ahyudanari, 2020). The HOR method consists of 2 stages, namely in HOR stage 1 it is used to determine the ARP value through severity, occurrence, correlation assessments. The calculation of the Aggregate Risk

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Potential (ARP) value is used to determine the priority of risk causes that need to be addressed first. The following is table 3 ARP ranking results.

Table 3. Aggregate Risk Potential (ARP) Ranking

Rank	Ai	Causes of Risk	ARP
1	A16	Thick sap content with low sugar content (HK) (< 82%)	1176
2	A17	Cooking temperature that is too high	1141
3	A2	Sugarcane sucrose (pol) levels are low, causing sugar product revenues to fall short of expectations	1057
4	A15	Inconsistent heating process when the sugar solution is concentrated	1035
5	A14	Unstable vacuum pressure on the vacuum pan	810
6	A1	Delay in delivery of raw materials from suppliers	792
7	A19	The crystal filter tool often tears in low grade fugal so that the sugar comes out with the solution.	786
8	A12	The exhaust steam pressure decreases so that it is unable to optimize the evaporation process.	768
9	A21	High mineral content in APK (boiler water) forms deposits	728
10	A5	The performance of the rotary vacuum filter tool for filtering sap from dirt is not yet optimal	680
11	A22	Boiler gasket installation that is not tightly closed	610
12	A13	The temperature is too high and the time is too long during the palm sap cooking process.	564
13	A4	The process of providing imbibition water (water to dissolve sugar content) which is not in accordance with SOP	546
14	A7	Pipe crust on sulfation is too thick	515
15	A10	The crust condition on the evaporator body is too thick, thus inhibiting the heat transfer process.	480
16	A3	Overload or burnout of the chain drive motor	405
17	A11	Pressure changes that occur in vacuum pipes continuously	264
18	A23	The fuel (dregs) used to produce heat has a high water content	260
19	A9	Preheater temperature not in accordance with SOP	229
20	A8	An imperfect carbonation process can leave residues that cause color in the product's sugar.	219
21	A20	In high grade fugal, sugar products have a high water content.	210
22	A24	High mineral content in APK (boiler water) forms deposits	189
23	A18	The motor that drives the rotary tool often burns out	189
24	A6	Excessive addition of lime milk to the defecation process	135
25	A25	APK (boiler feed water) contaminated with sugar so that the sugar sticks to the surface of the boiler and causes the steam pressure in the boiler to not be distributed properly.	110

$$ARP_j = O_j \sum S_j R_{ij}$$

$$ARP_{A16} = Occurace\ A16\ x\ ((S_{E2}\ x\ C_2) + (S_{E4}\ x\ C_4) + (S_{E6}\ x\ C_6) + (S_{E14}\ x\ C_{14}) + (S_{E15}\ x\ C_{15}) + (S_{E16}\ x\ C_{17}))$$

$$ARP_{A16} = 7\ x\ ((9\ x\ 7) + (3\ x\ 7) + (1\ x\ 9) + (3\ x\ 7) + (3\ x\ 9) + (3\ x\ 9))$$

$$ARP_{A16} = 1176$$

After the Aggregate Risk Potential (ARP) calculation is carried out, the next stage is to evaluate the risk. In this stage, risk ranking is carried out by selecting several risk agents that

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have the highest level of occurrence based on the Pareto Diagram analysis concept that will be mitigated based on the ARP value using the Pareto diagram. In accordance with the Pareto diagram concept, namely the 80/20 Pareto diagram, which means that 0-80% of the cumulative percentage value will be given a mitigation strategy proposal because the risk agent influences the occurrence of the risk event by 80% (Fitriani & Nugraha, 2022). The following is a Pareto diagram for each risk agent that has been processed data.

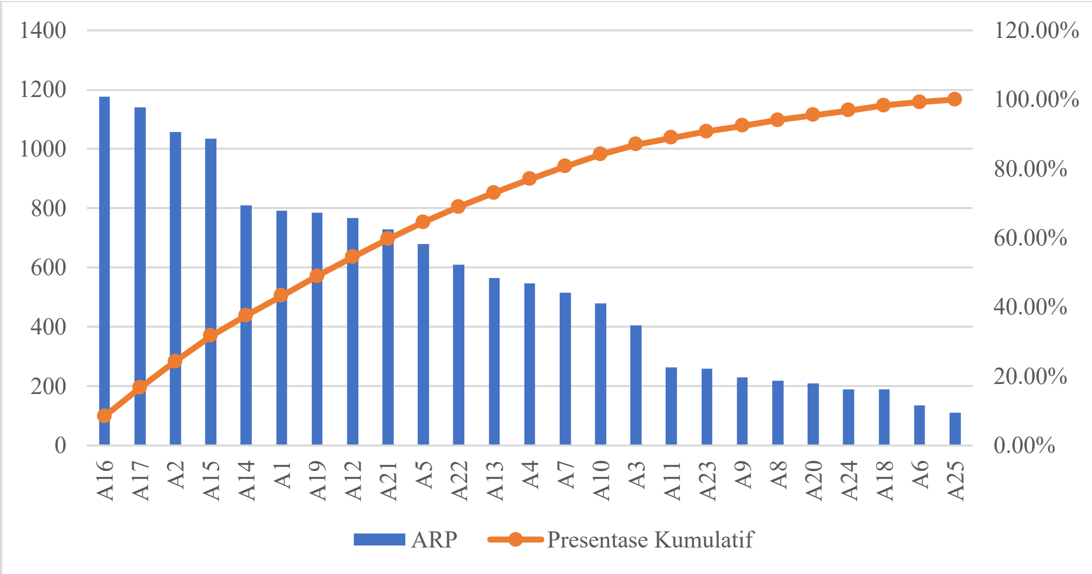

Figure 1. Pareto Chart Ranking

Reviewing the concept of the Pareto diagram above, it can be seen that the total risk agents are 13,898 with a total of 14 risk agents included in the group that dominates 80% with the total ARP value of 11,208 or 80.64% of the total ARP value of risk agents. After HOR stage 1 is carried out, the next step is HOR stage 2. In HOR stage 2, a mitigation strategy design will be carried out to prevent risk agents from arising in PT. XYZ's production activities. The design of risk mitigation actions is designed based on the results of HOR stage 1, namely 14 mitigation strategy designs will be carried out based on the number of dominant risk agents that have been calculated in the cumulative percentage of the Pareto diagram. The design of the proposed mitigation action strategy in HOR stage 2 is symbolized by PA and can be reviewed in table 4 below.

Table 4. Risk Mitigation Strategy Design

Risk Agent		**Proposed Mitigation Action Strategy**	
A16	Thick sap content with low sugar content (HK) (< 82%)	PA 1	Optimizing the pH setting process to achieve a Purity Value (HK) of 82% - 85%
A17	Cooking temperature that is too high	PA 2	Control the cooking temperature by periodically monitoring the performance of the vacuum pan to stabilize the cooking temperature.
A2	Sugarcane sucrose (pol) levels are low, causing sugar product revenues to fall short of expectations	PA 3	Conducting Sugarcane Selection and Quality Monitoring with a sugarcane grading system
A15	Inconsistent heating process when the sugar solution is concentrated	PA 4	Stabilization of waste steam to produce optimal heat temperature

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A14	Unstable vacuum pressure on the vacuum pan	PA 5	Control the vacuum pressure on the cooking pan vacuum so that it is stable
A1	Delay in delivery of raw materials from suppliers	PA 6	Optimization of sugarcane delivery scheduling and addition of sugarcane supply resources as reserves
A19	The crystal filter tool often tears in low grade fugal so that the sugar comes out with the solution.	PA 7	Performing Maintenance and Replacement on Low Grade Fugal Filters
A12	The exhaust steam pressure decreases	PA 8	Perform checks and maintenance on steam traps
A21	High mineral content in APK (boiler water) forms deposits	PA 9	Implement a demineralization system to reduce the mineral content in boiler feed water.
A5	The performance of the rotary vacuum filter tool for filtering sap from dirt is not yet optimal	PA 10	Improving the quality of the filter media through additional filters
A22	Boiler gasket installation that is not tightly closed	PA 11	Perform periodic inspection and replacement of gaskets
A13	The temperature is too high and the time is too long during the palm sap cooking process.	PA 12	Control the temperature and time during the palm sap cooking process.
A4	The process of providing imbibition water (water to dissolve sugar content) which is not in accordance with SOP	PA 13	Providing imbibition water in accordance with SOP standards, namely the imbibition water added reaches 20-30% of the total sugar cane entering the mill.
A7	Pipe crust on sulfation is too thick	PA 14	Perform regular pipe cleaning using scrap tools such as flexible cups (to clean scale)

After designing the mitigation action, the next stage is to calculate the correlation which aims to ensure that each designed mitigation strategy has a significant influence on the identified risk agents (risk sources). From this correlation, the calculation of the Total Effectiveness of Action (TEk) will be carried out, obtained from the multiplication of the Aggregate Risk Potential () of each risk agent with the correlation value between the risk agent and the mitigation strategy.

After obtaining the Total Effectiveness of Action (TEk) of each mitigation strategy, the next stage will be the difficulty of performing action (Dk). After that, the ETDk value will be calculated by dividing the values (TEk) and (Dk). The last stage of the HOR method stage 2 is to rank. This ranking is carried out based on the results of the calculation of the Level of Effectiveness and Level of Difficulty of each mitigation action. This ranking is carried out from the highest to the lowest ETDk value. The following is a table of the results of the mitigation action evaluation summary

Table 5. Summary of Mitigation Action Evaluation Results

Ranking	**PA**	**Mitigation Strategy**	**TEk**	**Dk**	**ETDk**
1	PA4	Stabilization of waste steam to produce optimal heat temperature	26727	3	8909
2	PA1	Optimizing the pH setting process to achieve a Purity Value (HK) of 82% - 85%	18979	3	6326
3	PA2	Controlling cooking temperature by periodically monitoring the performance of the	17694	4	5898

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		vacuum pan to stabilize the cooking temperature.			
4	PA9	Implement a demineralization system to reduce the mineral content in boiler feed water.	10686	3	3562
5	PA11	Perform periodic inspection and replacement of gaskets	12810	4	3203
6	PA8	Perform checks and maintenance on steam traps	9470	3	3157
7	PA7	Performing Maintenance and Replacement on Low Grade Fugal Filters	9105	3	3035
8	PA10	Improving the quality of the filter media through additional filters	8678	3	2893
9	PA6	Optimization of sugarcane delivery scheduling and addition of sugarcane supply resources as reserves	10845	5	3562
10	PA3	Conducting Sugarcane Selection and Quality Monitoring with a sugarcane grading system	8415	4	2104
11	PA12	Control the temperature and time during the palm sap cooking process.	5076	3	1692
12	PA5	Control the vacuum pressure on the cooking pan vacuum so that it is stable	6303	4	1576
13	PA14	Perform regular pipe cleaning using scrap tools such as flexible cups (to clean scale)	4635	3	1545
14	PA13	Providing imbibition water in accordance with SOP standards, namely the imbibition water added reaches 20-30% of the total sugar cane entering the mill.	1638	3	546

The following table summarizes the results of the calculation of the ETDk value from mitigation actions and an example of manual calculations to determine the ETDk value:

$$ETDk = \frac{TEk}{Dk}$$

$$ETDk1 = \frac{TPA1}{D1}$$

$$ETDk1 = \frac{18979}{3}$$

$$ETDk1 = 6326$$

Analytic Network Process (ANP) Method

In the Analytical Network Process (ANP) approach, the model development begins by defining the goal or main objective of the research. This goal is the final target to be achieved through decision making, for example risk mitigation in the sugar production process. The goal used in the ANP method is the resultacquisitionThe largest ETDk value at HOR stage 2 was atStabilization of waste steam to produce optimal heat temperature. Once the goal is set, the next step is to develop criteria that will be used to evaluate decision alternatives. These criteria often include factors such as benefits, opportunities, costs, and risks (BOCR).

In Analytical Network Process (ANP) using complex matrix calculations, called Super Matrix. The values obtained from the pairwise comparison matrix for each comparison between nodes and clusters will be calculated as a whole in the Super Matrix that can be explained. For the first unweighted super matrix which is a transformation of each pairwise comparison matrix value into one large matrix form. The following is the Unweighted Super Matrix in data processing using Super Decision Software.

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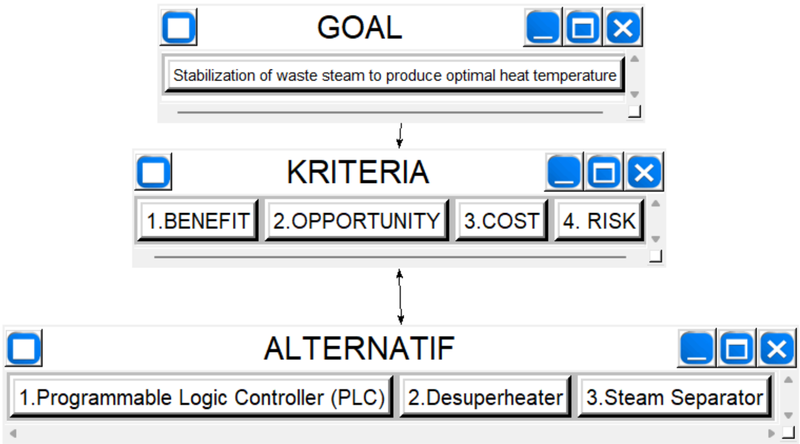

Figure 2. ANP Model Construction

Calculating Geometric Mean

The geometric mean calculation in the Analytical Network Process (ANP) method is used to combine or average the pairwise comparison assessments given by several respondents. From this Geometric mean calculation, the average value of the respondent's assessment will be obtained which will be inputted into the Super Dicision software. The pairwise comparison assessment in this study was carried out by experts consisting of the processing division manager, deputy manager of the Engineering division and head of production. The following are the results of the geometric mean calculation.

Table 6. Summary of Geometric Mean Calculation Results

Respondents	**R1**	**R2**	**R3**	***Geometric Mean***
Goal-->Criteria				
Benefits - Opportunities	2	3	4	3
Benefit - Cost	3	2	2	2
Benefit - Risk	4	4	3	4
Opportunity - Cost	4	3	5	4
Opportunity - Risk	5	6	6	6
Cost - Risk	2	3	2	2
Benefit-->Alternative				
PLC - Desuperheater	2	3	2	2
PLC - Steam separator	2	2	3	2
Desuperheater- Steam saparator	3	3	4	3
Opportunity-->Alternative				
PLC - Desuperheater	2	3	4	3
PLC - Steam separator	4	3	0.5	2
Desuperheater- Steam saparator	5	5	3	4
Cost --> Alternative				
PLC - Desuperheater	4	3	3	3
PLC - Steam separator	5	4	4	4
Desuperheater- Steam saparator	2	2	2	2
Risk --> Alternative				
PLC - Desuperheater	2	3	0.5	1
PLC - Steam separator	3	3	4	3

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Desuperheater- Steam saparator	3	4	4	4
Alternative 1--> Criteria				
Benefits - Opportunities	5	3	2	3
Benefit - Cost	2	2	2	2
Benefit - Risk	4	4	3	4
Opportunity - Cost	2	2	3	2
Opportunity - Risk	4	3	2	3
Cost - Risk	3	5	4	4
Alternative 2 --> Criteria				
Benefits - Opportunities	3	2	3	3
Benefit - Cost	2	4	3	3
Benefit - Risk	3	5	2	3
Opportunity - Cost	4	5	5	5
Opportunity - Risk	6	6	4	5
Cost - Risk	2	2	2	2
Alternative 3--> Criteria				
Benefits - Opportunities	5	4	4	4
Benefit - Cost	2	2	3	2
Benefit - Risk	3	4	3	3
Opportunity - Cost	2	3	3	3
Opportunity - Risk	2	2	4	3
Cost - Risk	0.5	2	2	1

Calculation Example*Geometric Mean*On node*Benefits*with*Opportunity* :

$$GM = \sqrt[n]{a_1 \times a_2 \times a_3 \dots a_n}$$
$$GM = \sqrt[n]{R_1 \times R_2 \times R_3}$$
$$GM = \sqrt[3]{2 \times 3 \times 4}$$
$$GM = 3$$

Data Processing Using Super Decision Software

In Analytical Network Process (ANP) using complex matrix calculations, called Super Matrix. The values obtained from the pairwise comparison matrix for each comparison between nodes and clusters will be calculated as a whole in the Super Matrix which can be explained (Samosir et al., 2021). Limiting Super Matrix is the result obtained in the Weighted Super Matrix then the weight is increased again with the overall eigenvalue of the cluster vector. The following is the Limiting Super Matrix in data processing using Super Decision Software.

Tabel 7. Limitation Super Matrix

Cluster Node Labels		ALTERNATIVE			GOAL	CRITERIA			
		Programmable Logic Controller	Desuper heater	Steam Separator	Stabilization of waste steam	Benefit	Opportunity	Cost	Risk
Alternative	Programmable Logic Controller	0.17252	0.17252	0.17252	0.17252	0.17252	0.17252	0.17252	0.17252
	Desuperheater	0.25572	0.25572	0.25572	0.25572	0.25572	0.25572	0.25572	0.25572
	Steam Separator	0.07176	0.07176	0.07176	0.07176	0.07176	0.07176	0.07176	0.07176
Criteria	Benefit	0.14948	0.14948	0.14948	0.14948	0.14948	0.14948	0.14948	0.14948
	Opportunity	0.20860	0.20860	0.20860	0.20860	0.20860	0.20860	0.20860	0.20860
	Cost	0.09254	0.09254	0.09254	0.09254	0.09254	0.09254	0.09254	0.09254
	Risk	0.04938	0.04938	0.04938	0.04938	0.04938	0.04938	0.04938	0.04938

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Based on the Limiting Super Matrix above, the value obtained that will be used to determine the priority of the selected alternative can be reviewed. In the Programmable Logic Controller PLC Alternative, the Limiting Super Matrix value is 0.172520; the Desuperheater Alternative gets the Limiting Super Matrix value of 0.255724; the Steam Separator Alternative gets the Limiting Super Matrix value of 0.071756. Then the Limiting Super Matrix for each criterion can be written sequentially as follows: in the Benefit Criteria, the Limiting Super Matrix value is 0.149484; in the Opportunity Criteria, the Limiting Super Matrix value is 0.208602; in the Cost Criteria, the Limiting Super Matrix value is 0.092535; in the Risk Criteria, the Limiting Super Matrix value is 0.049378. The results of the supermatrix limit values are then normalized by Cluster to assist in selecting the best alternative.

Table 8. Alternative Ranking

Ranking	Normalize	Alternative
1	0.51145	Desuperheater
2	0.34504	Programmable Logic Controller (PLC)
3	0, 14351	Steam Separator

Based on the results of the analysis using the ANP method with BOCR (Benefit, Opportunity, Cost, Risk) criteria, the best alternative prioritized in risk mitigation is the Desuperheater with a normalization value of 0.51145. This alternative has the most significant contribution in overcoming production risks, especially in stabilizing used steam to produce optimal heat temperatures. In second place is the Programmable Logic Controller (PLC) with a normalization value of 0.34504, which is recognized as effective in increasing automation and efficiency of the production process through integrated control. Meanwhile, the Steam Separator is in third place with a normalization value of 0.14351, which plays a role in improving steam quality and minimizing the risk of damage to equipment due to steam containing water.

Calculation Rate Agreement

An indicator of respondents' (R1-Rn) degree of appropriateness (agreement) with a problem in a single cluster is the rater agreement analysis. Using Kendall's coefficient of concordance (W; $0 < W < 1$), rater agreement is measured. According to Pratiwi et al. (2021), if the test value $W = 1$, it can be said that the respondents' assessment or opinion has complete conformance. On the other hand, if the value $W = 0$ or is approaching 0, it suggests that the respondents' answers differ or are inconsistent. The Normalised By Cluster findings of each respondent are used with the transposition, ranking, and W value calculation stages in the Rater agreement determination stage. The Alternative Normalised By Cluster values are summarised in the table below.

Table 9. Calculation Summaryrate agreement Alternative

U	6	S	14
MaxS	18	W	0.777778

Based on the calculation results of the Alternative rate agreement, the W value is 0.777778. In accordance with the Kendall's coefficient of concordance (W; $0 < W < 1$) tool used in measuring respondent agreement, it can be concluded that there is a match between respondent answers in selecting alternatives. Based on the calculation results of the Criteria rate agreement, the W value is 0.959064. In accordance with the Kendall's coefficient of concordance (W; $0 < W < 1$) tool used in measuring respondent agreement, it can be concluded that there is a match between respondent answers in selecting Criteria. Implementation of the Desuperheater Alternative will be placed on the steam distribution pipe by injecting cooling water before the steam is flowed into the production process. The water used in the

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desuperheater is feedwater from the economizer, which is water that is preheated in the economizer before entering the boiler. The sprayed cooling water will mix with the hot steam, thereby lowering the steam temperature until it reaches optimal saturation conditions.

Conclusion

Based on the results of the research that has been carried out, it was concluded that through this approachFocus Group Discussion(FGD) obtained 25 risk events (Risk event) and 25 sources of risk (Risk agent) which will be used to determine the mitigation strategy in the methodHouse Of Risk(HOR). From the ranking using the Pareto diagram principle on HOR 1, 14 dominant risk causes were obtained that would be proposed for improvement with an ARP of 1176 on (A16), namely the content of thick sap with low sugar content (HK) (<82%). Based on the results of the recapitulation of data processing results on HOR Stage 2, the highest ETDk value will be used as the goal in the ANP method. In ranking 1 with the Risk Mitigation strategy on PA 4, namely Stabilization of used steam to produce optimal heat temperature with an ETDk value of6326.Based on the calculation resultsrate agreementfor alternatives, the value obtainedKendall's Coefficient of Concordance (W) of 0.777778. This value indicates a fairly high level of conformity among respondents' answers in selecting risk mitigation alternatives. Meanwhile, for the criteria, the calculation results show a W value of 0.959064. Reviewing thisit can be concluded that the best alternative of the priority mitigation strategy assessment through the Analytic Network Process (ANP) method obtained the highest normalized value, namely the Desuperheater alternative of 0.51145, which is in accordance with the company's conditions and needs. The suggestion in this study is that in implementing the Desuperheater alternative, the company should provide training to employees, especially in the production sector, in operating the alternative.

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