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## HUMAN ERROR ANALYSIS TO REDUCE THE RISK OF WORK ACCIDENTS AT PT XYZ USING HEART AND FUZZY FMEA METHODS



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### Abstract

Human error is a significant contributor to workplace accidents in the manufacturing industry, particularly in the sugar production sector at PT XYZ, where specific challenges such as operator inexperience and equipment mismanagement heighten these risks. This study addresses a critical research gap by analyzing human error factors in the sugar production process using the HEART (Human Error Assessment and Reduction Technique) and Fuzzy FMEA (Failure Modes and Effects Analysis) methodologies. The HEART method quantitatively identifies human error probabilities at various production stages, while Fuzzy FMEA evaluates risk levels and prioritizes accident mitigation strategies. Key high-risk activities identified include improper use of the core sampler (HEP: 0.038, Fuzzy RPN: 500), data entry errors (HEP: 0.234, Fuzzy RPN: 120), and misoperation of the centrifugal machine (HEP: 0.304). The lowest risk was associated with slipping due to juice spills (Fuzzy RPN: 332). This innovative integration of HEART and Fuzzy FMEA offers a novel approach to developing effective mitigation strategies, including enhanced operator training, the establishment of standard hygienic sampling procedures, safety morning talks to raise awareness of safety, software training for operators, health checks before starting work, regular review and approval of data, weekly data audits, and the implementation of warning letters for frequent mistakes. By improving these safety systems, this research aims to significantly reduce accident risks and increase operational efficiency in the sugar industry.

**Keywords:** Error, HEART, Fuzzy FMEA, Workplace Safety, Risk Management

## INTRODUCTION

The sugar industry plays a significant role in both global and local economies, especially in tropical countries. However, its production process faces major challenges regarding occupational safety due to human error. According to data from BPJS Ketenagakerjaan in 2023, 56,603 reported work accidents in East Java, ranking second nationwide after West Java. This indicates the need for a human error analysis to help identify the causes of accidents and design effective prevention strategies. By understanding worker behavior and working conditions, companies can create safer and more efficient systems.

PT XYZ is one of the sugar factories equipped with modern technology and operates in two main phases: a 7-month production period and a 5-month machinery maintenance period. The number of work accidents at this factory drastically increased from 6 cases (January–July 2023) to 18 cases during the same period in 2024, indicating a 200% surge. These accidents range from minor injuries caused by a lack of focus when handling equipment to severe incidents such as falling from heights. This highlights the urgent need for research to reduce the risk of work-related accidents and improve occupational health and safety in the sugar production environment at PT XYZ.

Previous studies using SHERPA, HEART, and Fuzzy FMEA are mentioned briefly, but there is no critical evaluation of their findings, methodologies, or shortcomings. Without this, the Introduction misses an opportunity to position the present research more convincingly. Although these approaches have been applied in several industries, there has been no specific research that combines HEART and Fuzzy FMEA in analyzing work accident risks in the sugar industry. By integrating these two methods, this study is expected to provide a more comprehensive human error analysis. The objective of this research is to identify occupational accident risks, assess their severity levels, and formulate more effective mitigation strategies to reduce work accidents at PT XYZ.

## REVIEW OF LITERATURE

The International Ergonomics Association explains that ergonomics comes from the Greek word's "*ergon*", meaning "work", and "*nomos*", meaning "rules." Ergonomics can be defined as the study of human aspects in the working environment from anatomical, physiological, psychological, engineering, managerial, and design perspectives. In general, ergonomics is categorized into several fields, namely physical, cognitive, affective, environmental, and macro-organizational ergonomics (Hartono, 2018).

Occupational Safety and Health (OSH), also known as K3 in Indonesia, is an inseparable part of labour in a company. The role of OSH is essential to ensure the safety and well-being of workers, and beyond that, it has a positive impact on the sustainability of work productivity. Occupational safety refers to conditions free from potential accidents and hazards in the workplace, including building conditions, machine conditions, safety equipment, and the condition of workers themselves. Implementing an OSH system is expected to create a safe, comfortable, and environmentally friendly workplace, thereby minimizing or preventing work accidents and occupational diseases (Erviando et al., 2020).

Human error refers to mistakes made in performing specific tasks or jobs that can disrupt operational schedules or cause damage to objects and equipment. Such errors are a

major contributor to workplace accidents. Work accidents occur while an employee is working, resulting in injury or health disturbances. Hazards can arise anywhere, including in the workplace. A hazardous work environment can cause workers to feel unsafe and uncomfortable. Therefore, efforts to prevent work accidents must address human error problems among workers (Cahyani & Susilawati, 2024)

Risk management involves measuring or assessing risk and developing strategies to manage those risks. Risk management aims to manage emerging risks to create a reliable system while optimizing uncertainty. Risk management is typically divided into stages: risk planning, risk identification, risk handling, and risk monitoring and reporting (Basjir & Suhartini, 2019).

The HEART (Human Error Assessment and Reduction Technique) method is a human reliability assessment technique that helps identify risks or the main influences on human performance and the likelihood of errors using a systematic and repetitive approach (Zetli, 2021). In calculating Human Error Probability (HEP), the HEART method involves the following steps:

1. Determine generic categories (from A to H), each with a corresponding nominal human unreliability value. For example, category A has a nominal value of 0.55 and includes unfamiliar tasks performed quickly without understanding the potential consequences.
2. Identify Error Producing Conditions (EPCs). These are the factors causing the error and are classified accordingly. These factors influence how good conditions can deteriorate into poor ones.
3. Determine the proportion value (PoA). This value ranges from 0 to 1 (0 = Low, 1 = High). A value of 0 means the EPC does not influence the likelihood of error, while a value of 1 has a significant influence. Experts subjectively assess this.
4. Calculate HEP using the following formulas:

$$\text{HEP} = \text{NHU} \times \text{AE}_1 \times \text{AE}_2 \times \text{AE}_3 \times \text{AE} \quad (1)$$

$$\text{AE} = (\text{PoA} \times (\text{Total HEART Effect} - 1) + 1) \quad (2)$$

Where:

AE = Assessed Effect

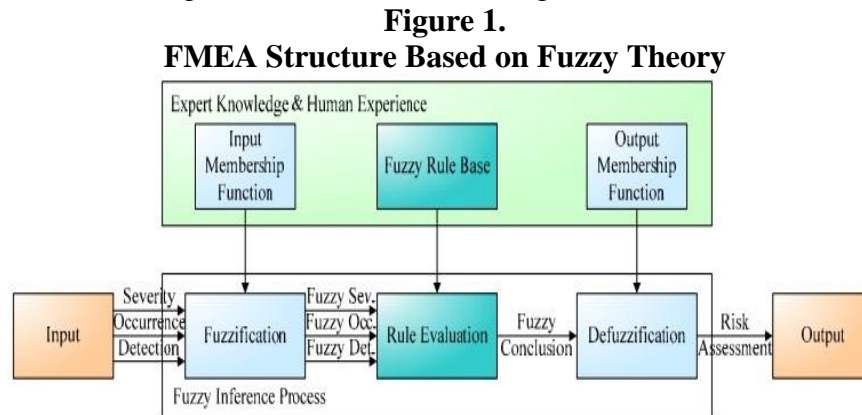
NHU = Nominal Human Unreliability

FMEA (Failure Mode and Effects Analysis) is a technique designed to identify potential failure modes before they occur by considering the risks and impacts associated with them. It is used to define, identify, and eliminate failures and issues in the processes, especially in production, whether already known or potentially present in the system. FMEA aims to identify failure modes, their effects, frequency, severity, risk level, and relevant actions to reduce those risks (Jamaluddin, 2024). One common method to measure criticality is the Risk Priority Number (RPN), which is calculated based on three parameters: occurrence, severity, and detection. The formula is:

$$\text{Risk Priority Number} = \text{Occurrence} \times \text{Severity} \times \text{Detection} \quad (3)$$

Fuzzy FMEA is a risk analysis method that combines traditional FMEA with fuzzy logic. It is used to identify and analyze potential failures in a system, product, or process, and to assess the impact and likelihood of those failures. Fuzzy logic transforms the FMEA index

ratings into linguistic variables, and fuzzy RPN outputs are obtained through if-then rules. The fuzzy-FMEA working scheme is illustrated in Figure 1.



Fuzzy FMEA Inference Process:

1. Fuzzification  
This involves defining membership functions for the crisp values determined by experts namely severity, occurrence, and detection into fuzzy severity, fuzzy occurrence, and fuzzy detection.
2. Rule Evaluation  
Using a fuzzy rule base, the obtained fuzzy values are processed through if-then rules during the rule evaluation stage.
3. Defuzzification  
The fuzzy values are then converted to crisp values to obtain the final Fuzzy-RPN, the product of the fuzzy criteria values.

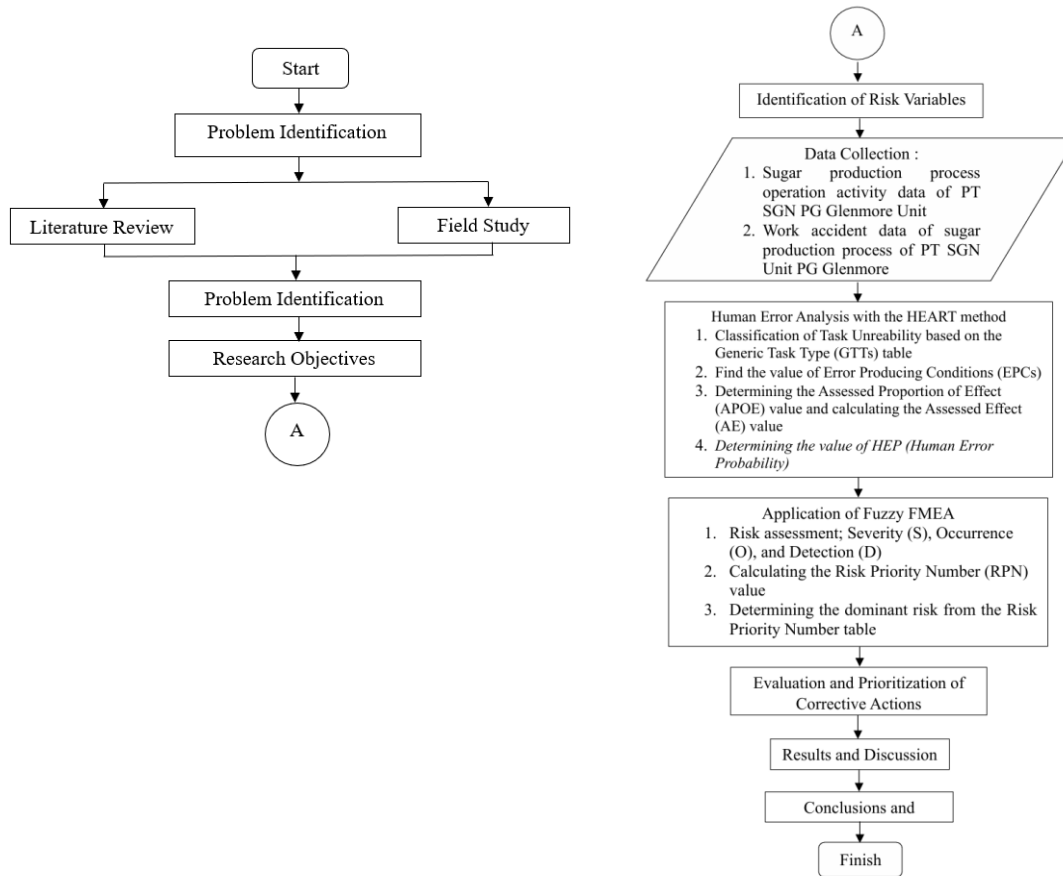
## RESEARCH METHOD

This research was conducted at PT XYZ starting in August 2024 and continued until the required data was collected. The variables used in this study include independent variables that may affect work during the sugar production process at PT XYZ. Meanwhile, the dependent variables are risk events, risk agents, and risk mitigation or proposed improvements related to the sugar production process at the same location.

Primary data for this research was obtained through observations and interviews with staff and supervisors from the HSE division. Secondary data consisted of previous studies, records of workplace accidents from 2023 and 2024, and documents related to the operational activities of the sugar production process at PT XYZ.

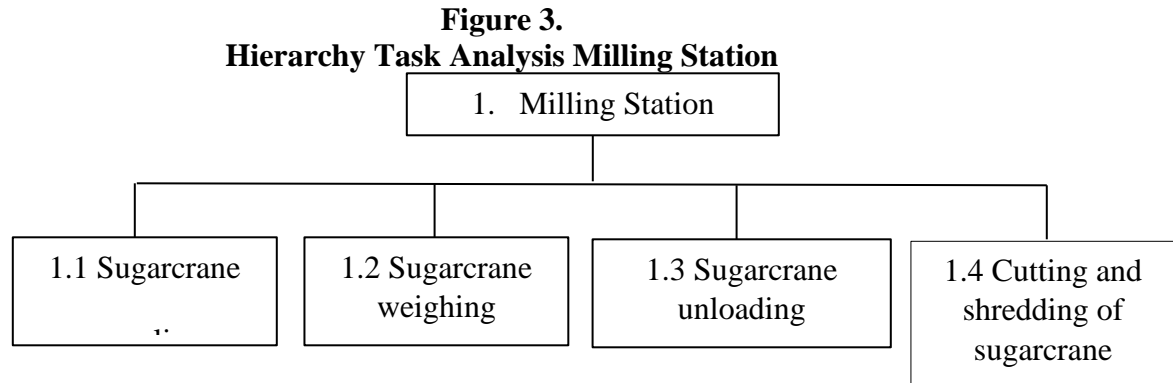
The stages of the research are illustrated in Figure 2.

**Figure 2.**  
**Research Flow Diagram**



## RESULTS AND DISCUSSION

The research results are broadly divided into human error analysis using the HEART method, fuzzy FMEA application, and evaluation of priority improvement actions. The human error analysis begins with identifying Hierarchical Task Analysis (HTA) conducted at 8 stations: the milling station, juice extraction, juice purification, evaporation, crystallization, carbonation, spinning, and generation. The HTA for each station is presented in diagram form, as shown in Figure 3, which is an example of HTA at the milling station.



From the results of field observations and interviews, each task was analyzed to obtain subtasks with critical phases that have the potential for human error, leading to workplace accidents, which consisted of 12 tasks. The subtasks with critical phases to be processed using the HEART method can be seen in Table 1.

**Table 1.**  
**Critical Phase**

No	Subtask	Task
1	Sugarcane sampling	
2	Sugarcane unloading	Milling station
3	Sugarcane cutting and chopping	
4	Sugarcane bagasse enters the mill	Juice extraction station
5	Raw sap screening	
6	Heating sugar juice	Sugar juice purification station
7	Transfer of concentrated juice from the evaporator to concentrated juice tank	Evaporation station
8	Cooking sugar juice	
9	Cooling sugar juice	Crystallization station
10	Addition of carbon dioxide (CO <sub>2</sub> ) and lime milk (Ca (OH) <sub>2</sub> )	Carbonation station
11	Sugar spinning	Turning Station
12	Burning bagasse as fuel	Power Generation Station

The identification and classification of task unreliability follows analysis of human error using the HEART method. The identification and classification of task unreliability are conducted to determine the type and category of tasks and to obtain the value of human unreliability based on the Generic Task Type (GTT) table. The determination of the type and

category of tasks is based on the results of field observations and interviews with workers and HSE supervisors at PG Glenmore, as shown in Table 2.

**Table 2.**  
**Categories of Subtasks based on Generic Task Type (GTT)**

No	Subtask	Type	Human Unreliability Value	Task Category
1	Sugarcane sampling	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
2	Sugarcane unloading	D	0,09	Simpler tasks that are performed quickly and do not require much attention
3	Sugarcane cutting and chopping	C	0,16	Difficult tasks that require high understanding and expertise
4	Sugarcane bagasse enters the mill	D	0,09	Simpler tasks that are performed quickly and do not require much attention
5	Raw sap screening	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
6	Heating sugar juice	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
7	Transfer of concentrated juice from the evaporator to the concentrated juice tank	C	0,16	Difficult tasks that require high understanding and expertise
8	Cooking sugar juice	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
9	Cooling sugar juice	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
10	Addition of carbon dioxide (CO <sub>2</sub> ) and lime milk (Ca (OH) <sub>2</sub> )	C	0,16	Difficult tasks that require high understanding and expertise
11	Sugar spinning	E	0,02	Routine work, trained work, fast work requiring not too high a skill level
12	Burning bagasse as fuel	D	0,09	Simpler tasks that are performed quickly and do not require much attention

The analysis of human error using the HEART method is followed by calculating EPC values to identify and measure the extent to which certain conditions contribute to human error. The determination of EPC values is based on the EPC table during interviews

describing the errors that occurred, and is reviewed from field observations and with the HSE supervisor of PG. Then, the analysis continues with establishing the Assessed Effect (AE) value determined based on factors such as task complexity, working conditions, and the potential impact of errors using formula 1. Based on the calculations, it is known that the subtask of sugar sampling obtained an AE of 1.9 and a HEP of 0.038, as seen in Table 3.

**Table 3.**  
**HEP Calculation**

No	Subtask	Description	No EPC	EPC Value	APOE	AE	HEP
1	Sugarcane sampling	The weakness of the feedback system is ambiguity	13	4	0,3	1,9	0,338
2	Sugarcane unloading	Doubt about the required performance standards	11	5	0,4	2,6	0,234
3	Sugarcane cutting and chopping	The lack of clarity regarding timeliness and direct confirmation of actions to be taken from the control system	14	4	0,3	1,9	0,304
4	Sugarcane bagasse enters the mill	Unreliability of equipment	23	1,6	0,3	1,18	0,1062
5	Raw sap screening	Lack of operator experience	15	3	0,3	1,6	0,032
6	Heating sugar juice	Hazards caused by limited physical capabilities	27	1,4	0,3	1,12	0,0224
7	Transfer of concentrated juice from the evaporator to the concentrated juice tank	The existence of a push to adopt other, more dangerous methods	21	2	0,4	1,4	0,224
8	Cooking sugar juice	Doubt about the required performance standards	11	5	0,3	2,2	0,044
9	Cooling sugar juice	The absence of a difference between the input of information and	19	2,5	0,3	1,45	0,029

No	Subtask	Description	No EPC	EPC Value	APOE	AE	HEP
		the truth of the verification					
10	Addition of carbon dioxide (CO <sub>2</sub> ) and lime milk (Ca(OH) <sub>2</sub> )	The need to make a definitive assessment that is beyond the capabilities and experience of the operator	24	1,6	0,3	1,18	0,188
11	Sugar spinning	Unreliability of equipment	23	1,6	0,4	1,24	0,0248
12	Burning bagasse as fuel	Unreliability of equipment	23	1,6	0,4	1,24	0,116

After obtaining the HEP values in the human error analysis, the research continues with a fuzzy FMEA application. At this stage, conventional FMEA calculations will be performed first, which will later be compared with fuzzy FMEA. The FMEA analysis is conducted by searching for severity, occurrence, and detection for each potential failure mode of every work activity. S, O, and D values are obtained from interviews with the HSE supervisor at PG Glenmore. Subsequently, the S, O, and D values are multiplied to obtain the RPN value using formula 3. The recapitulatory RPN values can be seen in Table 4.

**Table 4.**  
**Recapitulation of Conventional FMEA RPN**

No	Work Activity	Potential Failure Mode	Severity	Occurrence	Detection	RPN
1	Milling station	Improper use of the core sampler	4	5	6	120
2		Errors in data input into the system	3	4	7	84
3		Incorrect operation of the cane tippler	6	5	6	1
4		Workers injured by sharp objects	7	4	5	14
5	Juice extraction station	Body parts caught in the moving parts of the juice extraction machine	8	5	4	160
6	Sugar juice purification station	Errors in setting the temperature or pressure in the filtration system	6	5	6	180
7		Exposure to hot steam/splashes of juice	7	5	5	175
8	Evaporation station	Slipping due to spilled juice	6	6	5	180
9		Exposure to hot steam/splashes of juice	7	5	5	175

No	Work Activity	Potential Failure Mode	Severity	Occurrence	Detection	RPN
10	Crystallization station	Errors in operating equipment	5	4	6	120
11	Carbonation station	Leakage due to high CO2 pressure	8	4	5	160
12	Turning Station	Operational errors of the centrifugal machine	7	4	5	140
	Power Generation Station	Explosions and fires due to boiler operation errors	10	3	4	1

After calculating the RPN using conventional FMEA, the analysis was conducted using the fuzzy FMEA method. Fuzzy FMEA is a Mamdani or Min Max method that produces output in the form of values in the fuzzy set domain categorized in linguistic components. The analysis process involves creating functions for the variables, determining the membership functions for each input variable, and determining the FRPN, which can be seen in Table 5.

**Table 5.**  
**Comparison of RPN results between FMEA and fuzzy FMEA**

No	Potential Failure Mode	FMEA		Fuzzy FMEA	
		RPN	Priorities	FRPN	Priorities
1	Improper use of the core sampler	4	5	6	120
2	Errors in data input into the system	3	4	7	84
3	Incorrect operation of the cane tippler	6	5	6	1
4	Workers injured by sharp objects	7	4	5	14
5	Body parts caught in the moving parts of the juice extraction machine	8	5	4	160
6	Errors in setting the temperature or pressure in the filtration system	6	5	6	180
7	Exposure to hot steam/splashes of juice	7	5	5	175
8	Slipping due to spilled juice	6	6	5	180
9	Exposure to hot steam/splashes of juice	7	5	5	175
10	Errors in operating equipment	5	4	6	120
11	Leakage due to high CO2 pressure	8	4	5	160
12	Operational errors of the centrifugal machine	7	4	5	140
	Explosions and fires due to boiler operation errors	10	3	4	1

Based on the RPN calculations in Table 4, the highest risk of failure with fuzzy-RPN and RPN is found in the improper use of the core sampler, resulting in inaccurate sugar quality data with an FRPN of 500 and an RPN of 120. The second highest is errors in data input into the system, leading to production data discrepancies with an FRPN of 500 and an RPN of 84. The third highest is workers being exposed to sharp objects, resulting in physical injuries to workers with an FRPN of 500 and an RPN of 140. The fourth highest is body parts being exposed to moving parts of the extraction machine, resulting in physical injuries to workers with an FRPN of 500 and an RPN of 160. Lastly, operational errors of the equipment result in sugar crystal quality not meeting standards, with an FRPN of 500 and an RPN of 120.

The evaluation of fuzzy-FMEA results aims to understand the risk levels of each potential failure that has been identified. With the presence of FRPN values, it is possible to analyze which components or processes have high risks and require more attention. Priorities are set based on comparing FRPN values, where potential failures with the highest values become the main focus for immediate action. Prioritized corrective actions are then designed and implemented systematically, as shown in Table 6.

**Table 6.**  
**Improvement Recommendation for Highest Priority**

No	Potential Failure Mode	Corrective Actions
1	Improper use of the core sampler	<ul style="list-style-type: none"> <li>- Operator training due to the limited number of certified operators.</li> <li>- Establishment of standard hygienic sampling procedures</li> <li>- Safety morning talks to raise awareness of safety before operators begin their tasks.</li> </ul>
2	Errors in data input into the system	<ul style="list-style-type: none"> <li>- <b>Software training for operators.</b></li> <li>- <b>Health checks before starting work.</b></li> <li>- <b>Regular review and approval of data.</b></li> <li>- <b>Weekly data audits to enhance operators' awareness of their responsibilities.</b></li> <li>- <b>Implementation of warning letters for operators who frequently make mistakes.</b></li> </ul>
3	Workers injured by sharp objects	<ul style="list-style-type: none"> <li>- Safety morning talks to raise awareness of safety before operators begin their tasks.</li> </ul>
4	Body parts caught in the extraction machine	<ul style="list-style-type: none"> <li>- Safety morning talks to raise awareness of safety before operators begin their tasks.</li> <li>- Implementation of shifts considering operator productivity.</li> </ul>
5	Errors in operating equipment	<ul style="list-style-type: none"> <li>- <b>Intensive training for operators on equipment use procedures.</b></li> <li>- <b>Checklist for equipment inspection before the production process</b></li> </ul>

## CONCLUSION

Based on the research results, the study concludes that the risk of workplace accidents in the sugar production process at PT Sinergi Gula Nusantara PG Glenmore was assessed

using the HEART method. The highest Human Error Probability (HEP) values were associated with tasks such as sugarcane sampling (0.038), unloading (0.234), and cutting (0.304), while the lowest were linked to heating raw juice (0.0224) and adding CO<sub>2</sub> and lime (0.1888). The highest Risk Priority Number (RPN) was identified for improper use of a core sampler, resulting in inaccurate sugarcane quality data (FRPN 500, RPN 120), whereas the lowest risk was related to slipping due to juice spills (FRPN 332, RPN 180). Mitigation efforts proposed include operator training, the establishment of hygienic sampling procedures, regular health checks, and safety awareness initiatives to enhance operator responsibility and reduce accident risks in the production process.

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