



## RISK-BASED PERFORMANCE OPTIMIZATION OF MOZZARELLA CHEESE PROCESSING USING EXPERT JUDGEMENT – PREFERENCE SELECTION INDEX (PSI) MODEL

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### ABSTRACT

The failures of machines in the food processing plants tend to cause lower productivity, quality decline, and increased operation costs as a result of the unplanned downtime and loss of products. The production of mozzarella cheese is extremely sensitive to the reliability of equipment since its production is a thermal-mechanical process that needs to be controlled on a regular basis. This paper introduces a combined Expert Judgement-Preference Selection Index (EJ-PSI) model to consider and prioritize risks related to machine failures in the Mozzarella cheese processing. The relevance of decision criteria to the weighted relevance of the decision criteria was assigned by quantifying and normalizing expert evaluations of ten industry experts on the basis of experience, qualification, supervisory exposure, and audit involvement. The model considers three key systems, eleven key components, and twenty-one key failure modes, thus producing ranked risk profiles to prioritize maintenance. The findings show that the Moulder, Pre-Cooking & Cooking Stretching Machine and Stretching Machine are the most important systems that determine the throughput and the severity of defects. The EJ-PSI model facilitates the predictive maintenance planning process by determining the components that need to be addressed in time to prevent possible failures. The given model proves to be highly applicable in the context of complex production settings as it allows making decisions based on risks and minimizes variability in operations.



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### I. INTRODUCTION

The well structured and managed productive environment is vital to the production of high quality cheese that is in line with customer expectations and regulatory standards. The food industries are crucial in the management of the requirement of nourishment of the human beings. Food production, food processing, food packaging, food distribution and consumption are all included in the food industries. Government [1] has ignored the issue of increased population and its effect on food producing industries to a large extent. Food processing industry has a high rate of growth because of the increasing demand of high quality products. The standards such as Good Manufacturing practises (GMP), ISO 9000/22000, Hazard Analysis and Critical Control Points (HACCP), and Good Hygienic practices (GHP) are important to maintain the quality of the products and remain globally competitive. These practices are conducive to the health of consumers, increase the product acceptance, and correspond to the international food safety and hygiene standards. The ultimate goal is to drive the food industry to greater and more confident quality and safety measures. The contemporary food plants are operated on a round-the-clock basis, and even the failure of a single equipment may interfere with the production or the quality of the products.

This renders the planned and well-managed maintenance a necessity in order to regulate the downtime, ensure the quality remains constant, and to ensure the necessary output levels are maintained. Despite the popularity of FMEA in the field of mechanical and manufacturing industries to learn potential failures of machines and systems, its application in food processing remains rather limited. As the standards of safer and more high-quality food have increased, the application of FMEA to the sphere has become more significant. When correctly applied, it will assist in identifying the weak areas in the production line, aid in timely maintenance measures, and aid in efficient production as well as safer food handling. Lack of proper maintenance practices may have direct impacts on the quality and safety of food products in manufacturing plants. Research indicates that poor maintenance can severely reduce equipment efficiency; in a study case, a food company was operating at 55.30 percent efficiency, which is far below the accepted international standards [2]. Such a decline in efficiency increases the possibility of safety errors and quality flaws.

To prevent such problems, the companies should reinforce their maintenance strategy in such a way that machines do not fail and production is not disrupted by unnecessary causes [3]. The use of Failure Mode and Effect Analysis (FMEA) in food processing has gained more significance in enhancing the quality of products, safety, and facilitating operations without any hitches. FMEA is used in combination with other methods like Fault Tree Analysis and HACCP to identify the weak areas of equipments and processes in a systematic manner [4], [5]. By [6] emphasized on increased maintenance in food production and that the failure of equipment may lead to spoilage of the products and scraps in large volumes during line stops. Their research involved a review of failure and repair data of four pizza production lines, which involved descriptive statistics and compared performance among the lines. The findings revealed that time-to-failure and time-to-repair were both lognormally distributed, and the time-to-repair exceeding approximately 45 minutes was an indication of significant operational issues.

Failure Mode Effect Criticality Analysis (FMECA) is an analysis method that integrates the principles of FMEA with a criticality analysis that quantifies the impact of each failure mode on the performance of the system and safety of the product. The same strategy was used when a study on coconut oil processing was conducted and the criticality priority number was significantly improved by about 48.33 percent with the application of FMECA demonstrating the effectiveness of such method in refining maintenance and safety practices [7]. Multi-Criteria Decision Making (MCDM) is a field that is concerned with the assessment of multiple competing factors to assist decision-makers in selecting the most appropriate one in complicated cases. These techniques are used to make sure that the decisions are balanced, transparent and consistent by introducing various criteria into a single framework. In one of the applications, the Analytic Hierarchy Process (AHP) was applied to rank eight possible business partners based on financial and non-financial aspects [8].

AHP is still used to solve multi-criteria problems, as it assists the user to de-compose complex decisions and select the most sensible one, despite some weaknesses indicated [9]. Top Sigma is another method, which uses TOPSIS to rank options using an ideal and a worst-case reference. It is valued because it is easy and user-friendly though it may have difficulties with the weight assignment, disregarding relations between attributes, and can cause rank-reversal effects in certain cases [10], [11]. It may also be utilized in a group or in case of interval based data. Another popular technique is the Weighted Sum Model (WSM) [12]. The simplicity of its structure and speed of calculations make it appropriate when decisions are to be made with multiple criteria with various degrees of significance. The traditional FMEA has few disadvantages. The biggest problem is that it considers all the risk factors as having the same level of significance, which may misrepresent the significance of a failure mode.

Also, various combinations of severity, occurrence and detection may yield the same RPN value and it is more difficult to identify the issues that really require attention. FMEA is only applied on a rudimentary basis in the food industry. Small and medium food processors have many untrained employees, are not aware of structured risk-assessment tools, and do not have the time to analyze them in detail. The industry has its own complications as well like fluctuation of raw materials, strict hygiene regulations and high regulatory requirements that render the regular use of FMEA more difficult than in mechanical industries. In order to address these shortcomings, scholars have resorted to Multi-Criteria Decision-Making (MCDM) techniques, which are more flexible and more precise in ranking the risks [13]. One of the studies investigated the PSI approach to machining-related decisions, including the selection of materials or the cutting fluids, and compared it to other popular MCDM methods [14]. By adding the Expert Judgment (ExJ) component to the PSI model, it is possible to minimize the individual bias by combining the views of several experts and make the evaluation more balanced and representative.

Another issue that PSI approach circumvents is the issue of identical RPN value because normalized scores and weighted criteria are used to obtain clearer and more discriminative rankings. Reliability, Availability, and Maintainability (RAM) analysis is also essential in food production since it allows to reduce downtime, enhance the quality of products, and assist in safe and efficient operation [15], [16]. The current paper suggests a superior model that integrates the expert judgment and PSI method in an FMECA model. This is a combined methodology combining qualitative expertise and quantitative analysis to determine critical failure modes, establish realistic priorities and propose improvements. When it comes to a mozzarella cheese plant, the use of such MCDM-based methods will allow allocating resources more effectively, making more informed decisions, and enhancing the efficiency and sustainability. In this research work, Failure Mode Effect and Criticality Analysis (FMECA) model is a feasible method of analyzing risks and determining potential failure modes in systems, subsystems, or single components.

FMEA, FMECA, and MCDM techniques with an Expert-Judgment-based PSI method are the tools that can be used in a mozzarella cheese plant and each of them has its own benefits in risk assessment and decision support. FMEA can be used to identify possible failures in the production line and prioritize them according to their severity, frequency and detectability. It assists during the initial phase of risk assessment, but its findings may be affected by subjective scoring as well as its simplified assumptions. FMECA expands on FMEA with a criticality assessment, which enables a better assessment of the likelihood of each failure occurring and the intensity with which it can impact product quality or equipment performance. This renders it useful in detecting significant issues, including contamination or mechanical issues, but it may need considerable data and analysis. In the meantime, the MCDM tools like AHP, TOPSIS and VIKOR, with the assistance of the PSI method, offer a more comprehensive and flexible decision-making framework. The inclusion of expert opinions in the PSI process assists in handling multi-factor complex decisions, be it in the selection of suppliers, production planning, or sustainability enhancement.

This combination enables the consideration of both numerical and expert data, leading to more balanced decisions and more in line with the needs of operations. A combination of these methods will result in a more balanced approach to risk management and better performance of the plant. The Expert-Judgment PSI technique also solves a number of shortcomings of the traditional FMEA since it does not produce RPN-related discrepancies, lessens subjectivity, and provides more precise and dependable rankings

**II. METHODOLOGY**

Combining Expert Judgement (ExJ) with the Preference Selection Index (PSI) approach offers a powerful and systematic framework of ranking failure modes in mozzarella cheese production systems. The methodology is based on the domain knowledge of highly experienced staff members and at the same time a quantitative decision-evaluation framework is utilized. During the initial step, ExJ absorbs the experience of risk perception of the experts due to the operational exposure, machine behaviour, past failures and corrective measures in the industrial practice. These professional judgments are then transformed into decision matrices with regard to chosen criteria like Severity (S), Occurrence (O) and Detection (D), which minimizes the ambiguity in qualitative judgments. The PSI approach is then used to convert normalized expert data into objective risk-based ranking.

In contrast to traditional risk assessment methods that depend on the subjective scoring only, PSI removes the problem of inconsistency by calculating the variation of preference, the relative proximity to optimal performance, and the ranking of the components. This strategy reduces personal bias, prioritization of failures can be reproduced, and weight distribution is consistent. This integrated ExJ-PSI framework can be used in food processing systems where variation in quality and safety violations are caused by deviations in operations, like mozzarella cheese lines where the subsystems and components that are more likely to fail can be identified. This kind of prioritization leads to predictive maintenance scheduling, less downtime and better production reliability. Figure 1 shows the sequential methodological steps followed in this study that are data collection, expert scoring, normalization, PSI computation, and final ranking. The sequence of steps used in this analysis is illustrated in Figure 1.

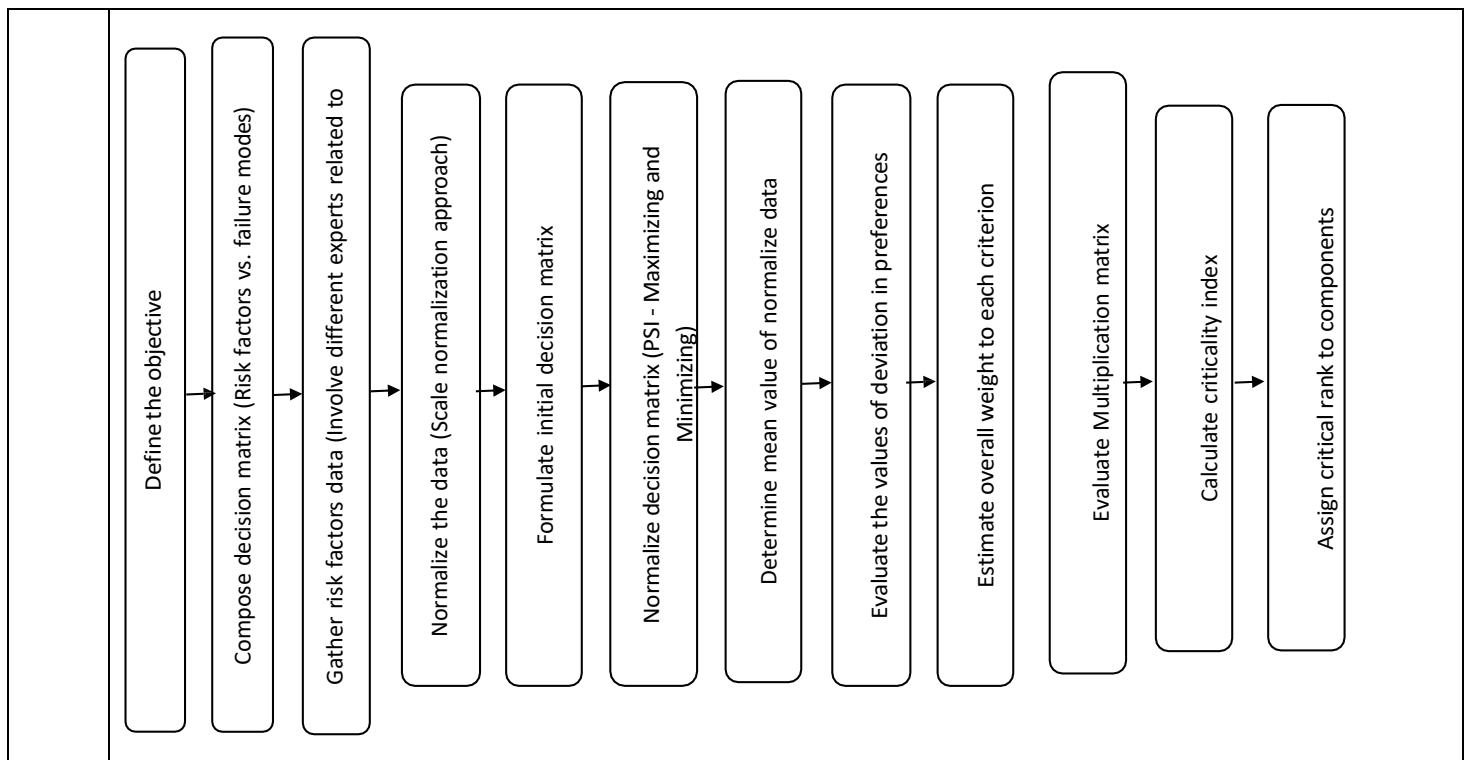


Figure 1: Structured approach for PSI using Expert Judgments.

Source: Authors, (2026).

**III. CASE STUDY OF SUBSYSTEMS/COMPONENTS IN MOZZARELLA CHEESE PLANT**

The case study is devoted to the assessment of key subsystems and key machine parts of a mozzarella cheese processing unit of an industry with a special emphasis on the determination of failure modes which directly affect productivity, reliability, and the quality of products. The process of mozzarella production has several consecutive and mutually dependent stages, including the creation of curd, pre-cooking, stretching, molding, cooling, brining and packaging. Each phase is assisted by specific machines and auxiliary systems whose operation leads to the overall performance of processing, energy consumption, and adherence to standards of consistency and hygiene.

Criticality analysis In order to examine the criticality, a combined Expert Judgement-Preference Selection Index (EXJ-PSI) framework was introduced to conduct systematic evaluation of the subsystem reliability. Technical operators, maintenance engineers and supervisory personnel who were well versed with the operational bottlenecks, historical breakdown trends and processes which were sensitive to safety were all inputted as experts. The obtained information was mapped to component-based failure modes, severity indices, detection patterns, and downtime impacts, which would be realistic to failure representation. Using EXJ-PSI, the research prioritizes machine-level risks that cause process interruptions, performance losses and non-uniformity of products.

The process that was followed in identifying subsystems, assessment, grading, standardization, and ranking is outlined in the following section. This systematic case- based study is the foundation of the maintenance planning, equipment tracking, and failure prevention in the processing of mozzarella cheese. Write in detail the research project, including background and limitations. The selection of materials and methods, procedures and equipment must be justified so that the work can be reproduced. Modifications or new methods must be described in detail. You must clearly define the universe and specify how the sample was selected and why it is representative. Data processing represents the practical development of a theoretical basis, deriving the model equations to program the calculation algorithm, according to the need. In materials, they include the technical specifications and the quantities, the origin and, if necessary, the method for its elaboration.

**III.1 STEPS FOLLOWED FOR INTERGRATED EXJ-PSI (EXPERT JUDGEMENT – PREFERENCE SELECTION INDEX)**

The three decision criteria were identified based on the severity of the failure mode (S), occurrence (O) and detection (D) which were summarized in Table 1, Table 2 and Table 3 respectively. The criteria reflect the extent of impact, the risk of failure recurrence and the chance of early detection respectively. The suggested integrated ExJ-PSI model proves to be very applicable in the analysis of complex equipment structures that have many subsystems, many components, and interacting failure modes [17], [18]. The methodological approach taken in this study is based on the methodological principles of the previous research by [19] and it is given as follows:

1. Decision Matrix Formulation - Determine the failure modes (FM) and evaluation criteria, i.e. Severity (S), Occurrence (O) and Detection (D), which were used to prioritize risks.
2. Expert Input Compilation - Gather information of experts and specialists in the domain and industry with similar machine setups and operational history, so that realistic depiction of past failures and maintenance patterns can be obtained.

Table 1: FMECA scale employed to identify severity (S).

Severity Level	Category	Description	Rank
1	Negligible	No noticeable effect on cheese quality, safety, or production.	1
2	Low	Minimal effect on cheese production, easily corrected.	2
3		Slight impact on production efficiency or cheese quality, but no major delays or rework needed.	3
4	Moderate	Reduced efficiency or minor impact on cheese quality, requiring some intervention or adjustment.	4
5		Moderate impact on production, causing some delays or noticeable quality variation.	5
6		Noticeable reduction in product quality or process efficiency, requiring significant rework.	6
7	High	Major disruptions in production or quality issues affecting customer satisfaction.	7
8	Major	Production halted for an extended period or significant batch quality loss.	8
9	Critical	Serious operational disruption, regulatory issues, or safety concerns.	9
10	Catastrophic	Complete system failure, severe safety risk, or major regulatory compliance breach.	10

Source: Authors, (2026).

Table 2: FMECA scale to rate occurrence (O).

Occurrence Level	Category	Description	Rank
1	Rare	Failure is extremely unlikely; no recorded incidents during plant operation.	1
2		Failure is highly unlikely; happens less than once in multiple years.	2
3	Low	Failure is infrequent; happens once every few years.	3
4		Failure is somewhat infrequent; happens about once per year.	4
5	Moderate	Failure is occasional; happens a few times per year.	5
6		Failure is somewhat frequent; happens about once a month.	6
7	High	Failure is frequent; happens multiple times per month.	7
8		Failure is very frequent; happens weekly.	8
9	Extreme	Failure occurs almost daily during operations.	9
10		Failure is nearly inevitable; happens multiple times per day without intervention.	10

Source: Authors, (2026).

Table 3: FMECA scale to rate detection (D).

Detection Level	Category	Description	Rank
1	Almost Certain	Failure is nearly always detected with current controls before it causes an issue.	1
2		Failure is very likely to be detected before causing significant effects.	2
3	High	Failure is likely to be detected under most conditions.	3
4		Failure is detected under specific conditions, but not consistently.	4
5	Moderate	Failure is occasionally detected; there is a moderate likelihood of detection before significant effects.	5

Source: Authors, (2026).

To minimize the uncertainty in assigning scales, multiple experts are involved in the process. Risk factor ranking data for all systems, components, and failure modes is gathered from multiple experts based on their years of experience, educational qualifications, quality audits undertaken, and the number of employees they have supervised as presented in Table 4.

The relative and overall weight values for the selected parameters have been calculated based on the weight values assigned to each expert. The overall weight values calculated are presented in Table 5.

3. Standardize the collected data and create the initial decision matrix 'A'. The normalized ranks for each failure mode are determined by combining the experts ranks with their corresponding overall weight values through multiplication. The various failure modes and causes of 14 systems are studied. A decision matrix is constructed for the failure modes of all components using these normalized ranks.

4. Normalize the values collected from industry experts by assigning weights to experts. The normalization process in the integrated Expert Judgment–Preferential Selection Index (ExJ–PSI) model is based on the linear normalization method outlined by [19]. After constructing the initial decision matrix using expert-weighted scores for each failure mode against criteria such as Severity, Occurrence, and Detection, the data are normalized to a common scale for comparability. This ensures that all risk factors are scaled consistently between 0 and 1, allowing for objective comparison across criteria and preventing any single factor from disproportionately influencing the results. Assign relative weights to each expert to reflect their influence on the final decision. The weight for each expert is based on the parameters listed above. These weights are normalized to derive overall expert weights. These weights are then used to adjust the expert scores in the subsequent steps.

5. Construct the initial decision matrix by considering failure mode and risk criteria. Combine expert scores (weighted by their expertise) for each failure mode and criterion to construct the initial decision matrix A. Specifically, expert ratings for each failure mode and risk criterion (Severity, Occurrence, and Detection) were collected using a standardized scale (typically 1–10). These individual expert scores were then weighted according to each expert’s qualifications, experience, and relevance to the study domain (as detailed in Table 4).

Table 4: Scale assign to expert weightage.

Sr. No	Scale assign to Experts	Experience in Years	Educational Background	Quality Audits Faced	No. of Employees Supervised	Scale
1	Novice (N)	<5	Matric passed	Faced less than 2 external audits	0-10	1
2	Competent (C)	5-10	ITI or Equivalent course in Food Safety/ Mechanical Engineering	Faced 2-4 external audits	10-20	2
3	Proficient (P)	10-15	Diploma in Food Safety/ Mechanical Engineering	Successfully faced 5–6 external audits with satisfactory feedback.	20-30	3
4	Expert (E)	15-20	Bachelor Degree in Food Safety/ Mechanical Engineering	Successfully faced 7–8 external audits with satisfactory feedback.	30-40	4
5	Master (M)	>20	Masters/ PhD in Food Safety/ Mechanical Engineering	Successfully faced more than 8- 10 external audits with excellent feedback.	40-50	5

Source: Authors, (2026).

Table 5: Scale overall expert weightage.

Expert No.	Experience in years		Employee under supervision		No. of Audits faced		Educational Background	Overall Weightage		
	Weightage	Relative weight	Weightage	Relative weight	Weightage	Relative weight		Weightage	Relative Weight	
Exp-1	4	0.1053	5	0.2273	5	0.1515	M.Tech	5	0.1613	0.1613
Exp-2	5	0.1316	3	0.1364	5	0.1515	B.E Instrumentation	4	0.1290	0.1371
Exp-3	3	0.0789	5	0.2273	5	0.1515	B.Tech Dairy	4	0.1290	0.1467
Exp-4	3	0.0789	1	0.0455	5	0.1515	B.E Electronics	4	0.1290	0.1012
Exp-5	5	0.1316	3	0.1364	5	0.1515	Diploma	3	0.0968	0.1291
Exp-6	1	0.0263	1	0.0455	4	0.1212	Diploma	3	0.0968	0.0724
Exp-7	2	0.0526	1	0.0455	1	0.0303	ITI	2	0.0645	0.0482
Exp-8	5	0.1316	1	0.0455	1	0.0303	ITI	2	0.0645	0.0680
Exp-9	5	0.1316	1	0.0455	1	0.0303	ITI	2	0.0645	0.0680
Exp-10	5	0.1316	1	0.0455	1	0.0303	ITI	2	0.0645	0.0680

Source: Authors, (2026).

The weighted average of these scores was calculated for each failure mode and criterion, resulting in the final numerical values  $a_{ij}$  used in the decision matrix (presented in Table 5). This process ensures a more objective aggregation of expert judgment and is now clearly detailed in the revised manuscript for transparency and reproducibility.

$$A = a_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{1}$$

Where  $a_{ij}$  is the index value.  $i=1,2,\dots,m$  along the row represents the failure modes and  $j=1,2,\dots,n$  represents the risk criteria's along the column.

6. Normalize decision matrix. The values are transformed in the matrix into a standardized scale so that all criteria are comparable. This step is necessary because different criteria often have different units or scales, and normalization ensures that no single criterion disproportionately influences the results.

For Maximization Problems

$$N_{ij} = \frac{a_{ij}}{a_{\max}} \tag{2}$$

For Minimization Problems

$$N_{ij} = \frac{a_{ij\min}}{a_{ij}} \tag{3}$$

$$A1 = [a_{ij}] = \begin{bmatrix} N_{11} & N_{12} & \dots & N_{1n} \\ N_{21} & N_{22} & \dots & N_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ N_{m1} & N_{m2} & \dots & N_{mn} \end{bmatrix} \tag{4}$$

7. Calculate the mean value of the normalized data

$$N = \frac{1}{m} \sum_{i=1}^m N_{ij} \tag{5}$$

8. Calculate the values of the variation of preferences between the values of every attribute

$$\theta = \frac{1}{m} \sum_{i=1}^m (N_{ij} - N)^2 \tag{6}$$

9. Calculate the deviations in the preference value for all criteria

$$\Omega_j = (1 - \theta_j) \tag{7}$$

10. Calculate the overall criteria weights for each criterion

$$w_j = \frac{\Omega_j}{\sum_{j=1}^n \Omega_j} \tag{8}$$

11. Prepare a matrix by multiplying  $N_{ij}$  and  $\omega_j$

12. Calculate the Criticality Index for all failure modes and all components.

13. Criticality rankings are given according to the value of CIPSI. When using Expert Judgment and the PSI model for ranking criticality, minimizing attributes during normalization involves ascending order, prioritizing failure modes with the lowest criticality index values to reduce minor risks. Conversely, maximizing attributes during normalization uses descending order, focusing on the highest values to address the most critical risks first. This ensures efficient risk mitigation and resource allocation.

Table 6 presents the various systems in Mozzarella cheese plant. The three most critical systems are assessed using the Failure Mode and Effect Analysis (FMEA) method, analyzed through the integrated Ex-PSI model. The process for determining the sequential ranking of the most critical components within these systems is conducted using the integrated Ex-PSI model. The detailed steps are explained in the later part of the section.

Table 6: Critical systems evaluated by integrated ExJ-PSI model.

Sr. No.	System	S	O	D	Criticality <sub>PSI</sub>	Rank
1	Pre-Cooking & Cooking Stretching Machine	6.0212	5.0212	2.6231	0.7136	2
2	Stretcher Cooker	5.6470	4.5505	2.7279	0.7507	5
3	Stretching Machine	5.2727	4.6470	3.4764	0.7178	3
4	Pakonna Machine	4.7279	5.1679	2.4985	0.7732	6
5	Moulder	6.3955	5.2488	3.4764	0.6383	1
6	Brine Tank and Circulation Pump	4.0212	4.0212	3.4764	0.8432	9
7	Finishing O Vat	4.5573	4.3925	2.6231	0.8243	8
8	Tumbler	3.8745	4.3536	1.8746	0.9580	14
9	Dicer Machine	4.3536	5.5003	1.8746	0.8500	12
10	Hassia Machine	5.1021	5.6470	2.2488	0.7526	4
11	Thermoforming Packaging Machine	4.0182	4.2878	2.9555	0.8473	13
12	Nitrogen Plant	4.1830	4.7668	3.2069	0.7856	7
13	Dicer Dispenser	3.8356	4.7668	3.1021	0.8188	10
14	Double O Vat	4.2878	3.9135	3.6859	0.8250	11

Source: Authors, (2026).

The analysis showed that there were three significant risk-critical systems on the production line, namely: (1) Moulder, (2) Pre-Cooking and Cooking Stretching Machine, and (3) Stretching Machine. Once the expert-based decision matrix was constructed, normalization was done to standardize expert assessment on all criteria. The difference in preference with each criterion was then measured by calculating the variance, which is the level of disagreement on the ratings by the experts. These amounts of variance were then transformed into deviation scores ( $\sigma$ ), representing the variation in the expert judgement. These deviations are used to calculate the complementary agreement measure ( $\Omega$ ) which is a measure of strength of agreement amongst experts.

The measures of agreement were standardized to produce criterion weights ( $w_j$ ) with attributes that had greater expert consensus having greater influence on the decision result. These weights were subsequently multiplied with the normalized failure mode scores ( $N_{ij}$ ) to calculate the final Criticality Index with the PSI-based formulation (CIPSI). This will mean that the more attributes of failure are agreed upon, the more ranking power they will have and thus enhance the reliability of prioritization. With this combined weighting and aggregation, the elements of all the three critical systems were ranked in an organized manner in terms of criticality of their failure. The result gives a systematic foundation to maintenance prioritization and reliability-oriented decision planning in mozzarella cheese processing facilities.

Table 7: Decision Matrix for PSI.

System	Component	Failure Order	Failure Mode	Failure Cause	Failure Effect	SV Severity	O Occurrence	D Detection
Moulder	Auger Gearbox	F1	Misalignment	Improper installation, deflection of shaft under load	Wear and tear, uneven wear and force distribution leading to premature failure	1.8746	3.0602	2.3536
		F2	Shaft Failure	Misalignment, Excess load, noise	Wear and tear of gearbox component	5.9974	4.9793	4.1650
		F3	Overheating	Improper lubrication	Gearbox and bearing damaged	3.8171	3.3380	4.4428
	Auger Motor	F4	Seal Failure	Oil seal leakage	Leakage in motor	3.6470	3.9165	4.2069
		F5	Deterioration of the bearing	Misalignment, Improper lubrication, Abnormal load	Excess friction and overheating, motor noise	5.9974	5.3619	5.0685
		F6	Electric Failure	Cable Short, motor trip	Motor fail	4.4613	3.6859	5.5154
	Chilled Water Pump	F7	Deterioration of the bearing	Misalignment, Improper lubrication, Abnormal load	Pump Failure	5.5184	3.5422	3.8326
		F8	Electric Failure of pump	The voltage supply to the pump is not correct	Failure of circuit breaker and winding burn	2.7279	2.1021	6.0364

	Ejector Plate	F9	Instrumentation Failure	PLC card problem, Water inside level switch	Pump Failure	4.9135	3.5393	6.7841
		F10	Mechanical failures	Plate bend, stud broken, Support rod bend	Moulder failure	4.9793	4.7098	3.8326
		F11	Instrumentation Failure	Sensor cable, Sensor springs	Plate failure	5.1830	2.9555	5.4526
Pre-Cooking & Cooking Stretching Machine	Feeding System	F12	Mechanical Failure	Wear and tear, material fatigue, lack of maintenance, or overloading.	Complete stoppage of curd feeding, reduced throughput, and production delays	3.9374	4.9793	5.4583
		F13	Motor or Drive System Failure	Electrical issues, mechanical overload, or motor burnout.	Inability to move curd into the machine, production halts, and potential damage to other components.	5.4583	3.5003	3.7698
	Pre-Cooking Section	F14	Temperature Sensor Malfunction	Sensor damage, calibration issues, or electrical faults.	Incorrect temperature readings, leading to inadequate or excessive heating	2.7279	5.0212	5.0212
		Temperature Control System	F15	Sensor Malfunction	Sensor degradation, electrical issues	Incorrect temperature control leading to poor cheese quality	3.8919	3.0567
	Water Circulation System		F16	Leakage	Worn-out seals, pipe corrosion	Loss of water pressure, potential water damage to equipment	4.5003	2.2488
		F17	Valve Malfunction	Mechanical wear, blockage	Inability to control water flow accurately	3.3536	3.8356	4.1650
	Motor and Drive System	F18	Electrical Faults	Aging electrical components, power surges	Motor failure, potential fire hazards	5.2488	4.8746	6.3536
	Stretching machine	Motor and Drive System	F19	Gearbox Failure	Insufficient lubrication, mechanical overload	Reduced efficiency, potential stoppage	6.9944	1.7279
Water Circulation System		F20	Pump Failure	Mechanical wear, electrical issues	Insufficient water flow, overheating of the product	5.8167	4.7698	5.8710
		F21	Leaks	Damaged pipes, loose connections, or faulty seals	Loss of water, reduced efficiency of the cooling system	2.9165	3.9165	5.7279

Source: Authors, (2026).

Normalized ranks are evaluated for all failure modes by considering experts overall weights. Decision matrix is created for all the components of identified most critical systems. Table 7 shows the decision matrix of three most critical systems i.e., for Moulder, Pre- Cooking & Cooking Stretching Machine and Stretching machine in mozzarella cheese processing plant. The normalized value of decision matrix is performed using above equation and the results are presented in Table 8. In multi-attribute decision-making methods, it is essential for attribute values to be dimensionless. This is accomplished by scaling each attribute to a range of 0 to 1, a process referred to as normalization. Moreover, all three parameters in this analysis are considered minimization criteria.

Table 8: Normalized decision matrix for PSI.

System	Component	Failure Order	SV	O	D
			Severity	Occurrence	Detection
Moulder	Auger Gearbox	F1	1	0.5646	1
		F2	0.3126	0.3470	0.5651
		F3	0.4911	0.5176	0.5298
	Auger Motor	F4	0.5140	0.4412	0.5595
		F5	0.3126	0.3223	0.4644
		F6	0.4202	0.4688	0.4267
	Chilled Water Pump	F7	0.3397	0.4878	0.6141
		F8	0.6872	0.8220	0.3899
		F9	0.3815	0.4882	0.3469
	Ejector Plate	F10	0.3765	0.3669	0.6141
		F11	0.3617	0.5846	0.4316
Pre-Cooking & Cooking Stretching Machine	Feeding System	F12	0.4761	0.3470	0.4312
		F13	0.3434	0.4936	0.6243
	Pre-Cooking Section	F14	0.6872	0.3441	0.4687
	Temperature Control System	F15	0.4817	0.5653	0.6777
	Water Circulation System	F16	0.4165	0.7683	0.6074
		F17	0.5590	0.4505	0.5651
Stretching machine	Motor and Drive System	F18	0.3571	0.3545	0.3704
	Motor and Drive System	F19	0.2680	1	0.3833
Water Circulation System	Water Circulation System	F20	0.3223	0.3623	0.4009
		F21	0.6427	0.4412	0.4109

Source: Authors, (2026).

The average values of the normalized data for each risk factor are computed.

$$NSV = 0.4643, NO = 0.5017, ND = 0.51819$$

The values of the variations of preference are calculated

$$\theta SV = 0.6064, \theta O = 0.6127, \theta D = 0.4413$$

The values of the deviation of variations of preference are calculated

$$\Omega SV = 0.3935, \Omega O = 0.3872, \Omega D = 0.5586$$

The overall criteria weights for all risk factors are calculated

$$\omega SV = 0.2938, \omega O = 0.2890, \omega D = 0.4171$$

After calculating overall weights, the result is obtained by preparing a matrix by multiplying  $N_{ij}$  and  $\omega_j$ . Table 9 shows the value obtained by multiplying  $N_{ij}$  and  $\omega_j$ .

Table 9: Multiplication matrix of  $N_{ij}$  and  $\omega_j$ .

System	Component	Failure Order	SV	O	D
			$N_{ij} \times \omega_j$	$N_{ij} \times \omega_j$	$N_{ij} \times \omega_j$
Moulder	Auger Gearbox	F1	0.2931	0.1632	0.5587
		F2	0.0918	0.1003	0.3157
		F3	0.1443	0.1496	0.2960
	Auger Motor	F4	0.1510	0.1275	0.3126
		F5	0.0918	0.0932	0.2594
		F6	0.1234	0.1355	0.2384
	Chilled Water Pump	F7	0.0998	0.1410	0.3431
		F8	0.2019	0.2376	0.2178
		F9	0.1121	0.1411	0.1938
	Ejector Plate	F10	0.1106	0.1061	0.3431
		F11	0.1063	0.1690	0.2412
Pre-Cooking & Cooking Stretching Machine	Feeding System	F12	0.1399	0.1003	0.2409
		F13	0.1009	0.1427	0.3488
	Pre-Cooking Section	F14	0.2019	0.0995	0.2619
	Temperature Control System	F15	0.1415	0.1634	0.3786
	Water Circulation System	F16	0.1224	0.2221	0.3394
		F17	0.1642	0.1302	0.3157
Stretching machine	Motor and Drive System	18	0.1049	0.1025	0.2070
	Motor and Drive System	F19	0.0787	0.2891	0.2141
Water Circulation System	Water Circulation System	F20	0.0947	0.1047	0.2240
		F21	0.1888	0.1275	0.2296

Source: Authors, (2026).

The values of the criticality index of each failure mode are obtained. Finally, the criticality index of a component is calculated by adding the values of the criticality index of all its failure modes. The same analysis was performed on all the 21 failure modes of the three critical systems of the mozzarella system in Table 10. The ranking of the components was then done according to their criticality index values and the findings of all the 11 chosen components in the three critical systems were tabulated in Table 12. Although several root causes were determined to cause the few failure modes, only the most important ones were taken into account in this study. Also, the values of the criticality index and their respective ranks were determined on some selected mozzarella systems.

The evaluation of the component criticality indices (CI) introduced in Table 11 allows identifying the most important systems that should be given special attention. The Pre-Cooking and Cooking Stretching Machine (CI: 3.2936) is the most important system, then there are the Moulder (2.3615) and the Stretching Machine (1.1231). In the Pre-Cooking and Cooking Stretching Machine, the most important component is the Temperature Control System (0.7686), and therefore predictive maintenance is necessary. The Moulder needs to attend to its Chilled Water Pump (0.6431) and Auger Motor (0.5732) whereas the Stretching Machine needs to look at the Motor and Drive System (0.6422). An organized maintenance plan according to these rankings can lead to better reliability, fewer failures and better operation efficiency.

Table 10: Critical ranks for failure modes.

System	Component	Failure Order	Failure Mode	Rank	Overall CI of Component	Overall CI of Sub- System (Failure modes)	Criticality Rank
Moulder	Auger Gearbox	F1	Misalignment	21	0.8742	5.5694	1
		F2	Shaft Failure	5	0.4278		
		F3	Overheating	15	0.5149		
	Auger Motor	F4	Seal Failure	14	0.5119		
		F5	Deterioration of the bearing	3	0.3787		
		F6	Electric Failure	7	0.4370		
	Chilled Water Pump	F7	Deterioration of the bearing	12	0.4969		
		F8	Electric Failure of pump	20	0.6022		
		F9	Instrumentation Failure	4	0.3979		
	Ejector Plate	F10	Mechanical failures	11	0.4728		
		F11	Instrumentation Failure	9	0.4553		
Pre-Cooking & Cooking	Feeding System	F12	Mechanical Failure	6	0.4201	3.4984	2
		F13	Motor or Drive System Failure	13	0.5040		
	Pre-Cooking Section	F14	Temperature Sensor Malfunction	7	0.4469		
Stretching Machine	Temperature Control System	F15	Sensor Malfunction	18	0.5876		
	Water Circulation System	F16	Leakage	19	0.5978		
		F17	Valve Malfunction	16	0.5302		
	Motor and Drive System	F18	Electrical Faults	2	0.3619		
Stretching machine	Motor and Drive System	F19	Gearbox Failure	17	0.5276	1.3820	3
	Water Circulation System	F20	Pump Failure	1	0.3666		
		F21	Leaks	10	0.4878		

Source: Authors, (2026).

The overall criticality indicator for each subsystem is calculated by aggregating the Criticality Index values of all individual failure modes within that subsystem. Specifically, a weighted summation approach is applied, where each failure mode's Criticality Index is multiplied by its respective weight—reflecting its relative importance or impact—and then summed to obtain the subsystem's overall Criticality Index. This method ensures that more significant failure modes contribute proportionally more to the subsystem's total criticality, providing a comprehensive view of system risk.

Table 11: Critical ranks for prominent critical systems.

System	Component	Overall CI of Component	Overall CI of Sub-System	Criticality Rank
Moulder	Auger Gearbox	0.5604	2.3615	2
	Auger Motor	0.5732		
	Chilled Water Pump	0.6431		
	Ejector Plate	0.5848		
Pre-Cooking & Cooking Stretching Machine	Feeding System	0.6522	3.2936	1
	Pre-Cooking Section	0.6851		
	Temperature Control System	0.7686		
	Water Circulation System	0.7091		
	Motor and Drive System	0.4787		
Stretching machine	Motor and Drive System	0.6422	1.1231	3
	Water Circulation System	0.4810		

Source: Authors, (2026).

Table 12: Comparative analysis of results for components of three critical subsystems.

System	Component	Rank by proposed model	Conventional RPN method	Normalized median
Moulder	Auger Gearbox	3	3	3
	Auger Motor	4	4	4
	Chilled Water Pump	7	8	6
	Ejector Plate	5	6	5
Pre-Cooking & Cooking Stretching Machine	Feeding System	8	9	7
	Pre-Cooking Section	9	5	9
	Temperature Control System	11	11	11
	Water Circulation System	10	10	10
	Motor and Drive System	1	1	1
Stretching machine	Motor and Drive System	6	7	8
	Water Circulation System	2	2	2

Source: Authors, (2026).

Comparison of results was done by using the Proposed Model, the Conventional RPN method, and the Normalized Median approach. The Normalized Median Rank provides a standardized measure that helps in comparing the criticality of failure modes across different systems or analyses. It aids in making informed decisions about where to focus resources for risk reduction and reliability improvement. The final results for the systems of the mozzarella cheese plant by the proposed integrated model (ExJ-PSI), conventional FMECA method and normalized median method is presented in Table 13.

Table 13: Comparative analysis of results for all subsystems.

Sr. No.	System	Rank by proposed model	Conventional RPN method	Normalized Median
	System	ExJ-PSI	Conventional RPN Rank	Normalized Median Rank
1	Moulder	1	1	1
2	Pre-Cooking & Cooking Stretching Machine	2	3	3
3	Stretching Machine	3	2	2
4	Stretcher Cooker	4	6	4
5	Hassia Machine	5	7	5
6	Pakonna Machine	6	8	6
7	Nitrogen Plant	7	4	7
8	Dicer Dispenser	8	12	9
9	Finishing O Vat	9	9	10
10	Double O Vat	10	5	8
11	Brine Tank and Circulation Pump	11	11	11
12	Thermoforming Packaging Machine	12	10	12
13	Dicer Machine	13	13	13
14	Tumbler	14	14	14

Source: Authors, (2026).

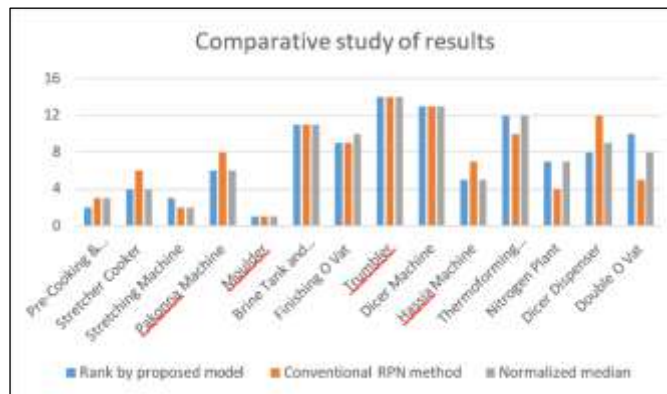


Figure 2: Comparative result of ranking of systems in Mozzarella cheese system.

Source: Authors, (2026).

The comparison between the rankings obtained with the proposed model, the traditional RPN method, and the normalized median values indicates that all the three methods determine the same key systems, summarized in Table 13. The ExJ-PSI method is more accurate with expert assigned weights which restricts the bias that is usually observed in conventional RPN scoring. Its normalization process also facilitates the comparison of various criteria on a similar scale that creates more definite and dependable risk priorities.

The approach also enhances efficiency in that it integrates the expertise with quantitative data in an organized manner, enabling the decision-makers to allocate resources faster and with more confidence. The ExJ-PSI model in practice is effective in complex settings like the mozzarella cheese processing where a combination of risk factors plays out. It is also very handy to both maintenance and quality teams due to its flexibility. In all three ranking techniques, the findings are similar.

The Moulder system is consistently ranked at Rank 1 which proves its significance in the entire process. The Stretching Machine remains on Rank 2 and the Pre-Cooking and Stretching Machine still remains at Rank 3. These consistent positions imply that such systems should be given priority to ensure a smooth and dependable running of plants. Minor variations in the rankings are observed when the normalized median values are compared with the suggested ExJ-PSI model and the classical RPN method. As an example, the Stretcher Cooker is ranked 4th in the proposed model and the normalized median approach, but 6th in the RPN approach, which indicates that its real risk could be more than the traditional RPN approach suggests. The same can be observed in the case of the Pakonna Machine, which is ranked 6th in the proposed and normalized ranking, but on the RPN one, the machine is ranked 8th, which indicates that there is a potential to misclassify the risk level.

Other statistically significant deviations are the Dicer Dispenser, which the proposed model ranks 8 th, the RPN method ranks 12 th and the normalized median method ranks 9 th. This diffusion means that the traditional RPN approach might underestimate its risk. The Nitrogen Plant is also inconsistent, keeping 7th position in the proposed and normalized approaches but increasing to 4th in the RPN method, indicating that statistical normalization offers a more consistent and realistic prioritization. The rankings of the Brine Tank and Circulation Pump (Rank 11), the Tumbler (Rank 14), and the Dicer Machine (Rank 13) have the same rankings in all three methods of evaluation, and there is a definite consensus that these systems are relatively less risky. The fact that the proposed model is close to the traditional RPN approach also contributes to the credibility of the new method. Simultaneously, the slight changes observed in the normalized median rankings suggest that statistical normalization can be added to identify subtleties that would otherwise be missed to provide the maintenance and risk-management choices with greater precision.

In comparison with FMEA and FMECA, the ExJ-PSI approach offers better grounds to prioritize failure modes within the setting like mozzarella cheese production. The conventional FMEA tends to generate duplicative RPN scores and does not distinguish between them, but ExJ-PSI uses expert-established weights and normalized factors to provide more consistent and less biased scores. FMECA is an improvement of FMEA with an element of criticality, yet it does not provide the flexibility and decision-making that are integrated in ExJ-PSI. With a combination of professional judgment and numerical scoring, ExJ-PSI method provides a more accurate prioritization, is more appropriate to food processing systems, and enhances the alignment of maintenance, reliability, and safety objectives. These results demonstrate the significance of periodically revising and enhancing the risk-assessment instruments to enhance the system performance and reliability of operation.

Figure 3 shows the summary of the work conducted on the mozzarella cheese system. The three most important subsystems i.e. Moulder, Pre-cooking and Stretching machine and Stretching machine of mozzarella cheese system is further analysed to rank the components on the basis of criticality. The results are categorized according to the level of criticality i.e. High criticality level, Moderate criticality level and low criticality level. The components with high criticality level that are ranked are Auger gearbox, Auger motor, Ejector plate, Motor and drive system, water circulation system and the Predictive based maintenance (PdM) and Condition based maintenance (CBM) plan is proposed to these components. Moreover, moderate criticality level components ranking evaluated are Chilled water pump, Feeding system, Pre-cooking system, Motor and drive system and the preventive maintenance plan is minimal is proposed to these components. These maintenance plan would be beneficial in terms of productivity with least break down and greatly enhanced the quality of cheese and the safety of the mozzarella cheese system.

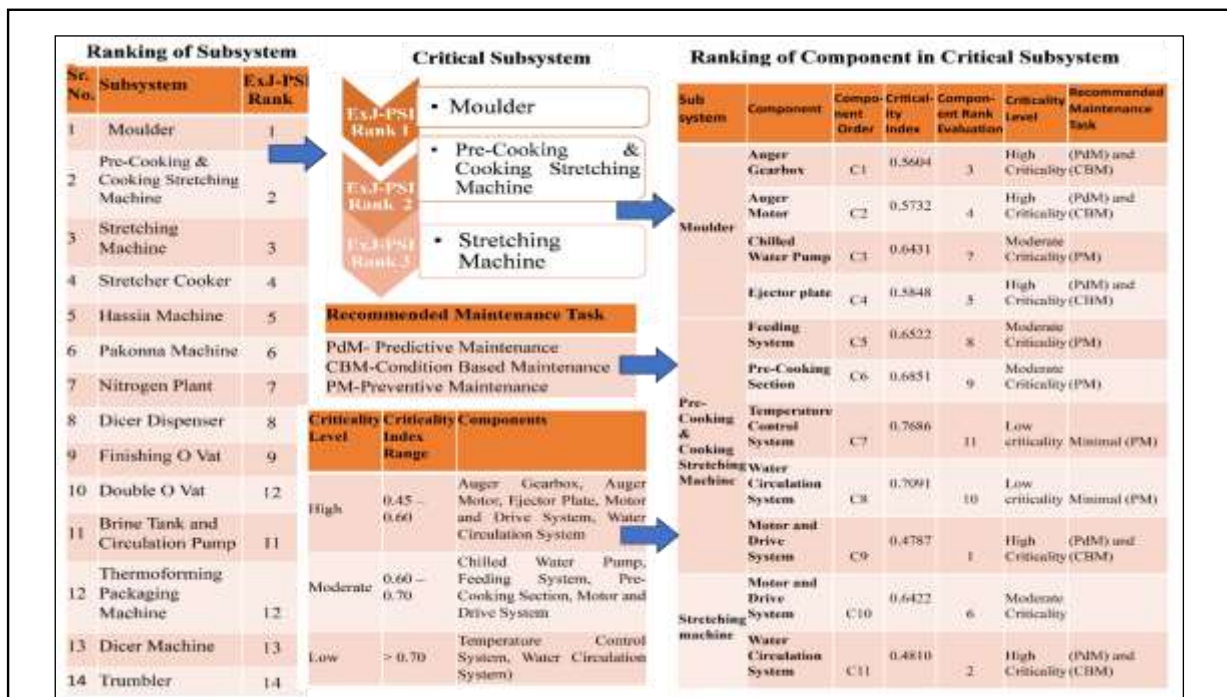


Figure 3: Summary of ranking of critical subsystem and components of critical subsystem with recommendation of maintenance task. Source: Authors, (2026).

#### IV. CONCLUSIONS

According to the analysis of the critical systems of an industrial mozzarella cheese facility, the integrated Expert Judgment-Preference Selection Index (ExJ-PSI) model was an effective and systematic way of detecting and prioritizing failure criticality. The methodology has succeeded in overcoming the limitations of the traditional FMECA-based ranking, especially the subjective scoring dispersion, disparity in weighting the criteria, and the ambiguity in evaluating the importance of failure. The most important conclusions made in this piece of work are as follows:

- The ExJPSI model defines plausible and bias-managed prioritization of failure modes. The framework reduced the variability in personal judgement by normalizing the opinions of several groups of experts, and converting them into objective weights, to achieve consistency in the evaluation. This method was very successful in solving close-ranking failure modes which could not be accurately differentiated by traditional RPN-based methods. The high congruence of the rankings obtained by ExJ-PSI and traditional procedures confirms its utility in the industrial environment and makes maintenance choices consistent with the operational risks that are realistic.
- Three systems were determined to be production-critical because of direct impact on the product formation and downstream reliability. The Pre-Cooking & Cooking Stretching Machine was the most important subsystem followed by the Moulder and the Stretching Machine. The research indicated that performance variability in these units has a major impact on the ultimate cheese structure, stretching behaviour, distribution of moisture and uniformity of the product. These results point to the necessity to distribute maintenance activities in a top-down fashion, starting with the subsystem that is most at risk.
- The component-level classification is a systematic maintenance roadmap to improve reliability. The critical components such as auger gearbox, auger motor, ejector assembly, and drive system need predictive or condition based maintenance to avoid failure. Items that are medium critical like water pumps, feeders, and pre-cooking units can be well handled by scheduled preventive servicing. Components with low criticality require simple routine checks. This classification also allows manufacturers to streamline the stocking of spare parts, maintenance schedules and staffing.
- The findings indicate that there are quantifiable industrial gains of implementing the ExJ-PSI-based ranking process. The strategy aids in minimizing unplanned stoppages, increased consistency in processes, greater use of assets, and greater forecasting of maintenance workload. Therefore, the ExJ-PSI model provides a scalable decision-support framework that can be generalized to other dairy-based processing systems and other multi-stage industrial equipment that needs the focus on reliability.

#### V. AUTHOR'S CONTRIBUTION

**Conceptualization:** Vaishali Talkit, Anand Bewoor and Amitkumar Shelar.

**Methodology:** Vaishali Talkit and Anand Bewoor.

**Investigation:** Vaishali Talkit and Amitkumar Shelar.

**Discussion of Results:** Vaishali Talkit, Anand Bewoor and Amitkumar Shelar.

**Writing – Original Draft:** Vaishali Talkit.

**Writing – Review and Editing:** Vaishali Talkit and Anand Bewoor.

**Resources:** Anand Bewoor.

**Supervision:** Anand Bewoor and Amitkumar Shelar.

**Approval of the Final Text:** Vaishali Talkit, Anand Bewoor and Amitkumar Shelar.

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