JURNAL AKUNTANSI, MANAJEMEN DAN EKONOMI
Vol. 27 No. 2, 2025, pp. 34-40
Published online in http://jos.unsoed.ac.id/index.php/jame
E-ISSN: 2620-8482

Integrated FMEA and FTA Approaches for Quality Control in False Eyelash Manufacturing

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Abstract

The synthetic eyelash manufacturing industry in Indonesia, particularly PT Hyup Sung Indonesia (HSI) in Purbalingga, faces ongoing challenges in maintaining product quality due to a high incidence of defects. This study aims to analyze and mitigate production-related risks through the application of Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). FMEA is utilized to systematically identify potential failure modes and prioritize improvement efforts based on the Risk Priority Number (RPN), while FTA is employed to trace the root causes of critical failures in a hierarchical structure. The FMEA results identified three major failure modes with the highest RPN values: knot misalignment during opening (RPN 150), insufficient application of adhesive (RPN 140), and curling of the knot during opening (RPN 140). FTA revealed that these issues primarily arise from equipment-related factors, operator handling methods, and inconsistencies in the oven-setting process. Based on these findings, several corrective actions are proposed, including the replacement of production tools (racks and brushes), installation of automatic timers, standardization of operating procedures, and operator training programs. The implementation of these measures is expected to reduce the risk of production failures and enhance the overall quality of synthetic eyelash products.

Keywords FMEA; FTA; Quality Control; Eyelash; Manufacturing

INTRODUCTION

The beauty industry in Indonesia has experienced rapid growth in recent years, with over 1,200 business entities recorded by early 2024 (Niaga Asia, 2024). This expansion is largely driven by increasing public awareness of personal appearance, alongside the growing influence of social media, particularly among women (Nawiyah et al., 2023). One of the most significantly expanding subsectors is the synthetic eyelash industry, which is characterized by intense competition, demanding both operational efficiency and continuous innovation to maintain market relevance.

PT Hyup Sung Indonesia (HSI), located in Purbalingga, is a leading exporter of synthetic eyelashes that operates under a make-to-order production system. A major challenge faced by the company is the high rate of product defects, which frequently exceeds the tolerance limits set by buyers. These quality issues result in costly rework, product rejections, and additional operational expenses. Contributing factors include operator errors, substandard raw materials, equipment wear, and suboptimal quality control systems. According to Andiyanto and Sutrisno (2017), the absence of an effective early detection mechanism can lead to recurring production failures. Gani et al. (2023) also emphasize the critical importance of root cause analysis in reducing defect rates and improving manufacturing outcomes.

To address these challenges, the study employs Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) as diagnostic tools. FMEA is a structured approach for identifying potential failure modes, evaluating their impact, and prioritizing corrective actions based on the Risk Priority Number (RPN) (Carlson, 2012). Meanwhile, FTA is applied to identify the root

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Received: February 2025
Revised: May 2025
Accepted: July 2025

causes of failures using a top-down, deductive reasoning process (Rochmoeljati & Nugraha, 2023). The integration of FMEA and FTA enables a comprehensive analysis of failure points and the formulation of targeted improvement strategies. Therefore, this study aims to analyze the failure modes in the synthetic eyelash production process at PT Hyup Sung Indonesia using FMEA and FTA methods, with the goal of providing actionable recommendations to mitigate production failures and enhance overall product quality.

RESEARCH METHODS

This study was conducted in the Production Department of PT Hyup Sung Indonesia, located at Jl. MT. Haryono, Dusun 3, Bojanegara, Padamara District, Purbalingga Regency, Central Java 53372, from January 6, 2025, to February 14, 2025. The research object is the synthetic eyelash production process at PT Hyup Sung Indonesia.

Two analytical methods were employed in this study to identify and analyze the quality-related problems encountered in the production process:

a. Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a systematic method used to identify and understand potential failure modes in a product or process, including their root causes and effects on the system or end-user. FMEA facilitates the assessment of the risk level associated with each failure mode, allowing teams to prioritize corrective actions accordingly (Carlson, 2012). To assess the risk of failure, each failure mode is evaluated based on three main parameters:

1. Severity

Severity measures the seriousness of the failure's impact on production. The greater the impact, the higher the assigned score. The severity score can only be reduced through changes in the process. Table 1 presents the severity assessment criteria used in this study:

Table 1. Severity Rating Criteria

Effect	Product Impact Criteria (Customer)	Rating	Process Impact Criteria (Manufacturing/Assembly)
Failure to Meet Safety and/or Regulatory Requirements	Failure mode affects vehicle operation and/or fails to meet regulations, without warning.	10	Endangers operator without warning.
Failure to Meet Safety and/or Regulatory Requirements	Failure mode affects safe vehicle operation and/or fails to meet regulations, with warning.	9	Endangers operator with warning.
Loss of Primary Function	Loss of primary function (vehicle cannot be operated).	8	100% of the product must be scrapped. Production line stops.
Reduction in Primary Function	Function is reduced (vehicle can operate, but with reduced performance).	7	Some products must be scrapped. Deviation from main process.
Loss of Secondary Function	Loss of secondary function (vehicle operates, but comfort features do not function).	6	100% of production must be reworked off-line.
Reduction in Secondary Function	Reduction of secondary function (vehicle operates, but comfort features are degraded).	5	Some production must be reworked off-line.
Annoyance >75% of Customers	Appearance/sound is not as expected; more than 75% of customers notice.	4	100% of the product must be reworked at the previous station. Some must be reworked before processing.
Annoyance ~50% of Customers	Appearance/sound is not as expected; ~50% of customers notice.	3	Minor disruptions to process; some rework needed at the station before processing.
Annoyance <25% of Customers	Appearance/sound is not as expected; <25% of customers notice.	2	Minor disturbance to process, operator, or operation.
No Effect	No noticeable effect.	1	No observable effect.

(Sumber: Carlson, 2012)

2. Occurrence

Occurrence refers to the frequency with which a potential failure mode is likely to occur. The more frequently it occurs, the higher the rating assigned. Table 2 presents the occurrence rating criteria used in this study:

Table 2. Occurrence Rating Criteria

Possible Failure	Criteria: Causal Event – PFMEA (Incidents per Item)	Rating
Very High	≥100 per 1.000 (≥1 in 10)	10
Very High	50 per 1.000 (1 in 20)	9
High	20 per 1.000 (1 in 50)	8
High	10 per 1.000 (1 in 100)	7
Moderate	2 per 1.000 (1 in 500)	6
Moderate	0.5 per 1.000 (1 in 2.000)	5
Low	0.1 per 1.000 (1 in 10.000)	4
Low	0.01 per 1.000 (1 in 100.000)	3
Very Low	≤0.001 per 1.000 (1 in 1.000.000)	2
Very Low	Failures are eliminated through preventive controls	1

(Sumber: Carlson, 2012)

3. Detection

Detection assesses the likelihood that a failure will not be detected by existing control mechanisms. The greater the chance that a failure goes undetected, the higher the assigned rating. Table 3 presents the detection rating criteria used in this study:

Table 3. Detection Rating Criteria

Detection Opportunity	Criteria: Likelihood of Detection by Process Controls	Rating	Likelihood of Detection
No Detection Opportunity	No process control; cannot be detected or analyzed.	10	Almost Impossible
Detection Not Possible at Any Stage	Failure mode and/or cause is very difficult to detect (e.g., random audits).	9	Very Remote
Problem Detected After the Process	Detected after the process by the operator through visual, tactile, or auditory checks.	8	Remote
Problem Detected at the Source	Detected at the station by the operator using attribute measurement tools (e.g., go/no-go gauges, manual torque) or after the process.	7	Very Low
Problem Detected After the Process	Detected after the process by the operator using variable measurement tools or at the station (e.g., go/no-go gauges, manual torque).	6	Low
Problem Detected at the Source	Detected at the station by the operator or automatic controls that alert the operator (e.g., lights, buzzers), including setup verification and first piece inspection.	5	Moderate
Problem Detected After the Process	Detected after the process by automatic controls that identify and lock nonconforming parts to prevent further processing.	4	Moderately High
Problem Detected at the Source	Detected at the station by automatic controls, and the part is immediately locked to prevent further processing.	3	High
Error Detection/Prevention	Automatic detection and prevention at the station to ensure the part cannot be manufactured with defects.	2	Very High
Not Applicable; Error Prevention	Error is inherently prevented by design of tools, machines, or products; defects cannot occur due to fail-safe design.	1	Almost Certain

(Sumber: Carlson, 2012)

b) Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is an analytical method used to illustrate the interrelationships among various causes within a system. This analysis is presented in the form of a top-down diagram that maps the pathways and logical connections leading to a top event, typically a system failure or an undesirable occurrence. These causal pathways are represented using standard logic symbols (Carlson, 2012).

According to Hauptmanns and Werner (1991), the general steps in constructing a Fault Tree Analysis (FTA) are as follows:

a. Identification of the Top-Level Event

This step involves defining the top event, such as coolant loss or hazardous material release. A thorough understanding of the system's functions, structure, and scope is essential for accurate identification.

b. Construction of the Fault Tree

The tree is developed in a top-down manner, beginning with the top event and branching downward to the basic causes. Logical relationships between events are represented using standard logic gates such as AND, OR, and NOT.

c. Analysis of the Fault Tree

This stage involves identifying the minimal cut sets—combinations of basic events that could lead to the top event—and, if needed, calculating the probability of the top event. The analysis may be qualitative or quantitative, providing insights for risk mitigation and enhancing system reliability.

RESULTS AND DISCUSSION

1. Risk Identification

Risk identification aims to determine the type of failure at each stage of the production process or workstation. Data is obtained through field observations and interviews with employees who are directly involved. The identified failure risk data can be seen in Table 4. below:

Table 4. Risk Identification

No	Workstation	Failure Mode	No	Workstation	Failure Mode
1	Knotting	Uneven distance between knots	7	Untying	Paper tears when opened
		Cross-pattern too narrow			Knotting curls when opened
		Loose knot tension			Knotting shifts or misaligns
2	Adhesive Application	Excessive application of adhesive (ethyl acetate)	8	Shape Cutting	Uneven cutting
		Insufficient application of adhesive (ethyl acetate)			Cut is too short
3	Brushing	Knotting thread breaks			Dull scissors
		Loose thread not properly tightened			Damaged dimension marking template
		Base fabric becomes scorched	9	Scissors Cutting	Cut is too short
		Damage to ironing equipment			Resulting size does not match the model
4	Rolling	Cross-pattern becomes invisible			Dull scissors
		Knotting breaks during rolling	10	Planting (Assembly)	Misalignment with planting reference points
		Knotting misaligned during rolling			Knotting exposed to glue during planting
5	Tying	Roll loosens during tying			Incorrect cutting of thread between knots
		Thread pulled from knotting	11	Gluing (Mounting)	Knotting falls apart or breaks
		Tie is too tight			Excessive glue application
6	Oven	Knotting becomes burnt			Decreased glue quality
		Short circuits or electrical issues	12	Packing & Finishing	Barcode does not match production period
		Damaged dynamo			Damaged or torn carton box
		Malfunctioning alarm and sensor			Damaged or torn inner box
					Dirty plastic cover

2. Risk Assessment

The questionnaire was distributed to 3 different respondents for each production stage, then each questionnaire result value was grouped to find the Severity Index, Occurrence Index, and Detection Index. After that, the Risk Priority Number (RPN) was calculated by multiplying Severity, Occurrence, and Detection. Table 5. below presents the results of the RPN calculation for each failure mode:

Tabel 5. Calculate *Risk Priority Number*

No	*Failure Mode*		INDEX			RPN			RPN
			S	O	D	S	O	D	
1	*Knotting*	Uneven spacing between knots	23%	43%	20%	3	5	2	30
2	*Knotting*	Cross-pattern too narrow	23%	47%	20%	3	5	2	30
3	*Knotting*	Loose knot tension	30%	43%	20%	3	5	2	30
4	Adhesive Application	Excess adhesive (ethyl acetate)	33%	30%	80%	4	3	8	96
5	Adhesive Application	Insufficient adhesive (ethyl acetate)	40%	47%	70%	4	5	7	140
6	Brushing	Knotting thread breaks	20%	67%	20%	2	7	2	28
7	Brushing	Loose thread not fully tightened	23%	60%	23%	3	6	3	54
8	Brushing	Base fabric scorched	40%	37%	20%	4	4	2	32
9	Brushing	Damage to ironing tool	77%	27%	20%	8	3	2	48
10	Rolling	Cross-pattern disappears	87%	50%	30%	9	5	3	135
11	Rolling	Knotting breaks during rolling	57%	53%	23%	6	6	3	108
12	Rolling	Knotting misaligned during rolling	57%	50%	23%	6	5	3	90
13	Tying	Roll loosens during tying	83%	20%	17%	9	2	2	36
14	Tying	Knotting thread pulled	87%	50%	30%	9	5	3	135
15	Tying	Tie is too tight	37%	30%	53%	4	3	6	72
16	Oven	Knotting burnt	60%	33%	17%	6	4	2	48
17	Oven	Short circuit/electrical issues	30%	47%	23%	3	5	3	45
18	Oven	Damaged dynamo	90%	23%	23%	9	3	3	81
19	Oven	Malfunctioning alarm/sensor Paper tears during untying	13%	20%	23%	2	2	3	12
20	Untying	Knotting curls when opened	93%	57%	13%	10	6	2	120
21	Untying	Knotting shifts	100%	70%	13%	10	7	2	140
22	Untying	Uneven cut	93%	43%	23%	10	5	3	150
23	Shape Cutting	Cut is too short	50%	33%	17%	5	4	2	40
24	Shape Cutting	Dull scissors	90%	20%	17%	9	2	2	36
25	Shape Cutting	Damaged marking template	53%	33%	20%	6	4	2	48
26	Shape Cutting	Cut is too short	63%	27%	27%	7	3	3	63
27	Scissors Cutting	Size mismatch with model	67%	37%	20%	7	4	2	56
28	Scissors Cutting	Dull scissors	57%	40%	20%	6	4	2	48
29	Scissors Cutting	Misalignment with reference points	63%	57%	20%	7	6	2	84
30	Planting (Assembly)	Glue touches knotting during planting	20%	57%	10%	2	6	1	12
31	Planting (Assembly)	Incorrect thread cut between knots	67%	33%	13%	7	4	2	56
32	Planting (Assembly)	Knotting breaks/falls apart	90%	27%	10%	9	3	1	27
33	Gluing (Mounting)	Excessive glue application	67%	47%	10%	7	5	1	35
34	Gluing (Mounting)	Reduced glue quality	80%	23%	47%	8	3	5	120
35	Gluing (Mounting)	Barcode mismatch with period	47%	40%	47%	5	4	5	100
36	Packing & Finishing	Damaged/torn carton box	43%	27%	30%	5	3	3	45
37	Packing & Finishing	Damaged/torn inner box	80%	20%	20%	8	2	2	32
38	Packing & Finishing	Dirty plastic cover	53%	20%	23%	6	2	3	36
39	Packing & Finishing	Uneven spacing between knots	53%	56%	26%	6	6	3	108

3. Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) analysis is conducted based on the identification of failure modes that appear in the false eyelash production process. The following is Table 6. which presents a list of failure modes, effects, causes, current controls, as a basis for creating a Fault Tree Analysis (FTA).

Table 6. Results of FMEA for the False Eyelash Production Process

No	*Failure Mode*		*Potential Effects of Failure*	*Potential Causes of Failure*	*Current Controls*
1	*Knotting*	Uneven spacing between knots	Requires rework by operator	Lack of concentration or operator inexperience	Periodic visual inspection by QC; significant defects returned for rework
		Cross-pattern too narrow	Requires rework by operator	Incorrect knotting technique	Periodic visual inspection by QC; visibly narrow motifs returned for rework
		Loose knot tension	Imprecise spacing, requires tightening	Insufficient thread tension during knotting	Thread tension is adjusted before knotting begins
2	Adhesive Application	Excessive adhesive (ethyl acetate)	Results in overly stiff product	Operator inaccuracy; poor brush quality	Adhesive is applied based on operator estimation and habit
		Insufficient adhesive (ethyl acetate)	Weak adhesion; poor structural integrity	Operator inaccuracy; poor brush quality	Adhesive is applied based on operator estimation and habit
3	Brushing	Knotting thread breaks	Product failure or needs to be rejoined	Excessive tension; poor thread quality	Broken-thread products are set aside or rejoined if possible
		Loose thread not fully tightened	Curled lashes	Operator does not tighten thread before brushing	Operator attempts to align threads carefully before brushing
		Scorched base fabric	Obstructed vision for operator	Iron temperature too high or dirty tool	Operator reduces heat and cleans the iron when necessary
		Ironing tool damage	Delayed process for repair/replacement	Continuous use and tool aging	Repair or replacement of the iron as needed
4	Rolling	Disappeared cross-pattern	Product is defective and irreparable	Untidy brushing process	Visual inspection by QC; defective units are separated
		Knotting breaks during rolling	Product is defective and irreparable	Poor hair quality	Visual inspection by QC; broken units are separated
		Misaligned knotting during rolling	Reworkable if not severe	Incorrect hair positioning during rolling	Misaligned products are reworked if possible
5	Tying	Roll loosens during tying	Deformed shape, unbindable	Poor rolling or low-quality paper	Returned for rework in rolling process
		Knotting thread pulled	Structure becomes unstable	Thread unintentionally pulled during tying	Operators handle rolls carefully before tying
		Tie is too tight	Deformed product shape	Excessive tying pressure by operator	Tightness still based on operator habit and estimation
6	Oven	Burnt knotting	Product is unusable	Oven temperature too high	Oven temperature set based on operator experience
		Short circuit or electrical issues	Process stops, hazardous	Unsafe electrical installation	Technicians called for electrical issues
		Damaged dynamo	Process stops awaiting repair	Component wear or poor maintenance	Dynamo repaired if possible or replaced
		Malfunctioning alarm or sensor	Overheating risk and product damage	Sensor not calibrated or broken	Operator relies on time estimation for heating
7	Untying	Torn paper during untying	Paper unusable; product damaged	Poor or aged paper quality	Replace unusable paper with new sheets
		Curled knotting during untying	Product is defective and irreparable	Overheating in oven or poor hair quality	QC visually inspects and separates curled knotting
		Misaligned knotting	Deformed shape, lost motif	Poor handling before, during, or after oven	QC inspects and returns misaligned knotting for rework if possible
8	Shape Cutting	Uneven cut	Unclean final appearance	Operator cutting error	QC inspects regularly and returns uneven cuts for rework
		Cut is too short	Product unusable	Operator cutting error	Short lashes are separated
		Dull scissors	Jagged or rough cuts	Worn scissors	Sharpening tools provided; replaced if necessary
		Damaged dimension template	Inaccurate cutting	Template damaged by scissors or pressure	Template replaced if severely damaged
9	Scissors Cutting	Cut is too short	Product unusable	Operator cutting error	Short lashes are separated
		Incorrect sizing	Product rejected	Inaccurate trimming against model specs	QC inspects and separates off-spec products
		Dull scissors	Jagged cuts	Worn scissors	Replace scissors when no longer usable
10	Planting	Misaligned with reference points	Returned to operator for correction	Lack of precision in tweezers handling	QC inspects regularly; misaligned units returned for correction
		Knotting exposed to glue during planting	Knotting damaged; requires replacement	Glue placed too close to lash line	QC inspects; contaminated units are separated

Based on the results of the FMEA analysis of the false eyelash production process, three failure modes were found with the highest Risk Priority Number (RPN) values. The first position was occupied by the knotting failure shifted in the untying process with an RPN of 150. The other two failures with a high RPN of 140 occurred in the process of applying adhesive fluid and returning to untying (curly knotting when opened). The high RPN in these three failure modes indicates that the stages of applying adhesive fluid and untying are critical points that greatly Determine the success of the overall production results.

4. Fault Tree Analysis (FTA)

The following are the results of Fault Tree Analysis (FTA) for three major problems in the false eyelash production process based on the highest RPN value in the FMEA analysis. This analysis describes the root cause of each failure that occurs, so that it can be the basis for designing appropriate corrective steps.

a. Fault Tree Analysis Shifted Knotting

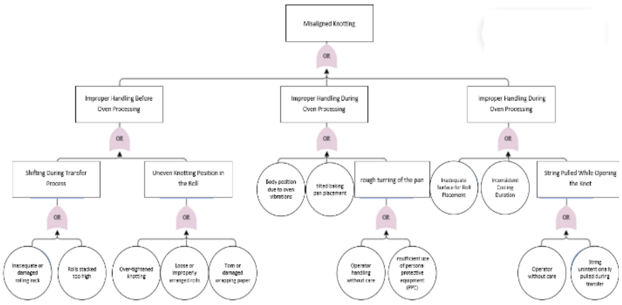

Figure 1. FTA Diagram of Shifted Knotting

Shifted knotting is a damage that changes the position of hair strands that have been tied during the production process, especially at the transfer, oven, and post-oven stages. In this FTA, errors can come from three main points, namely before the oven, during the oven, and after the oven.

b. Fault Tree Analysis Too Little Adhesive Liquid (ethyl acetate) Given

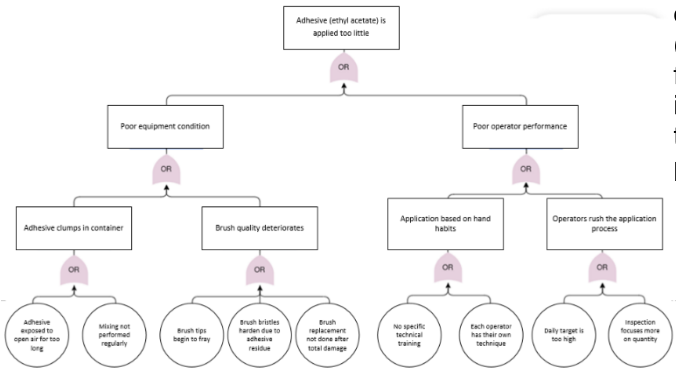

Figure 2. FTA Diagram of Too Little Adhesive Liquid Given

The process of applying adhesive liquid aims to glue the hair knots and maintain the shape of the eyelashes when heated. If too little adhesive liquid is given, the adhesive power decreases so that the knot structure can come loose or is not strong enough to withstand heating.

c. Fault Tree Analysis Knotting Curly when Opened

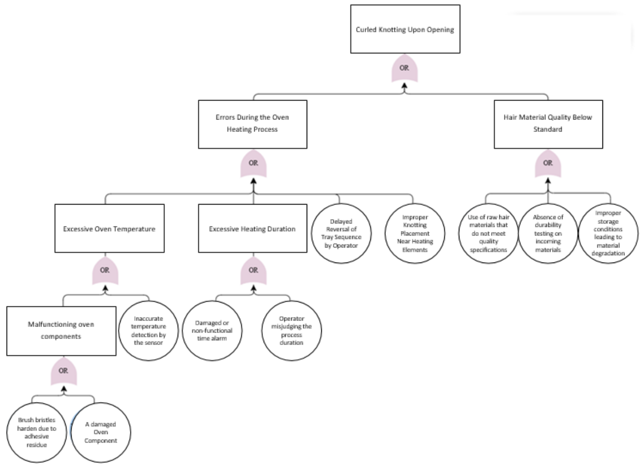

Figure 3. FTA Diagram of Dry Knotting When Opened

The problem of curly knotting when opened has two main causal factors, namely errors during the heating process in the oven and inappropriate hair quality.

5. Improvement Proposal

The improvement proposal is analyzed based on the basic event in the Fault Tree Analysis (FTA) diagram that has been prepared. The following is Table 7. which presents the improvement proposal aimed at overcoming the cause of failure at each stage of the process.

Table 7. Improvement Proposal

No.	Root Cause	Proposed Improvement
1	Roll transfer rack is not in proper condition	Replace or repair the rack with sturdy materials and easy-to-move wheels
2	Rolls are stacked too high	Add tiered racks to ensure safer and more organized storage
3	Ties are too tight	Standardize tie tension using assistive tools or retraining
4	Rolls become loose or untidy	Recheck neatness before the oven process and fix any issues
5	Paper is damaged or torn	Use higher GSM paper and check quality before use
6	Operators are rushing	Reschedule daily targets to be more realistic, provide buffer time between processes
7	Lack of proper PPE	Provide complete PPE such as heat-resistant gloves, masks, and aprons; conduct regular PPE usage inspections
8	Strings get tangled during transfer	Use trays or containers when moving rolls, handle with more care
9	Liquid is exposed to air for too long	Close liquid containers after use, use sealed containers when not in use
10	Stirring is not done regularly	Establish batch-wise stirring procedures, set stirring schedule with a timer
11	Brush tips are starting to fray	Replace brushes regularly, use brushes made from more durable materials
12	Brush bristles harden due to adhesive residue	Clean brushes at the end of each shift, soak in special cleaning solution
13	Brushes are only replaced after severe damage	Create a preventive brush replacement schedule at fixed intervals
14	No special technique training provided	Standardize brush application techniques or provide retraining
15	Each operator has their own brushing style	Standardize brush application techniques or provide retraining
16	Daily targets are too high	Review maximum hourly capacity and re-evaluate targets
17	Quality check focuses only on quantity	Evaluate performance based on quality, not just production volume
18	Damaged components in the oven machine	Perform regular maintenance and daily inspections, replace unfit components
19	Electrical issues in the oven	Check electrical installations regularly, call an experienced technician if issues arise
20	Hair raw materials are below standard	Implement incoming material inspections with minimum quality specifications
21	No durability test on raw materials	Add a durability test stage before mass production
22	Improper storage of hair materials	Develop a storage system based on standard temperature and humidity in a closed warehouse

CONCLUSION

This study on quality control in the production process of false eyelashes at PT HSI using the FMEA and FTA methods concludes that a total of 34 failure modes were identified through the FMEA analysis. Among these, three failure modes with the highest Risk Priority Numbers (RPN) were prioritized for immediate corrective action: misaligned knotting when opened (RPN 150), insufficient application of adhesive (RPN 140), and curled knotting upon opening (RPN 140). These issues significantly affect the final product quality and require urgent handling to prevent recurring defects and ensure consistent production standards.

The Fault Tree Analysis (FTA) revealed that the root causes of these critical failure modes originate from a series of interconnected basic events. The misalignment of knotting results from placing the knotting too close to the oven's heating element, vibrations during the heating process, and errors in tray placement or locking. The insufficient adhesive application is caused by the use of damaged brushes, absence of standard procedures for applying and mixing the adhesive, and inconsistent operator habits. Additionally, curled knotting is triggered by excessive heat, substandard hair material, and lack of heating time control.

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