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Failure Risk Analysis in the Plastic Yarn Production Process Using the FMEA Method and Kaizen Approach

Ananda Bayu Dewantara[1], Said Salim Dahda[2]
[1.2] Department of Industrial Engineering, Faculty of Engineering, Universitas Muhammadiyah Gresik
Jl. Sumatera No.101, Gn. Malang, Randuagung, Kec. Kebomas, Kabupaten Gresik, 61121
Email: bayuavanue@gmail.com , said_salim@umg.ac.id

ABSTRACT

The manufacturing industry is a key pillar in global economic growth, yet the risk of failure remains a crucial challenge. PT XYZ, a plastic yarn manufacturer in Gresik, faces similar challenges despite achieving success. The production process is not yet optimal, with a defect rate exceeding the standard limit. This research utilises the FMEA and Kaizen approaches to identify priority failure modes and propose improvements. Analysis indicates that yarn spot defects are the top priority for correction, attributed to insufficient pump pressure. Proposed improvements based on the Risk Priority Number include installing pressure control devices, implementing preventive maintenance, and providing support facilities for operators. Therefore, these improvements are expected to enhance the efficiency and the quality of the plastic yarn production process at PT XYZ Gresik.

Keywords: *Diagram Pareto, Diagram Fish Bone, FMEA, Kaizen*

Introduction

Industrial development has become the main support for global economic growth, covering various sectors ranging from technology to manufacturing. [1]. As one of the main sectors in the global industry, manufacturing continues to develop significantly to answer growing market demand. [2]. Despite innovation and efficiency efforts, the risk of failure remains a major challenge facing the product manufacturing industry. [3]. Factors such as the introduction of new technology, instability in the supply of raw materials, and the complexity of the production process trigger the risk of failure. [4]. In facing these challenges, the company emphasises failure prevention as the main focus. They strive to implement proactive and innovative strategies to reduce risks and ensure smooth operations and product quality. [5].

The PT XYZ company operates in the plastic thread manufacturing industry sector. Based in Gresik, this company has become an important supplier for various industrial sectors. Specialising in the production of plastic thread, PT XYZ is known as a manufacturer that produces high-quality products for the global market. Despite achieving success, PT XYZ faces various complex failure risk challenges along the production line. This can be seen from the fact that there are still failures in the production process, which result in defects. The following is the check sheet data for PT XYZ's plastic thread production:

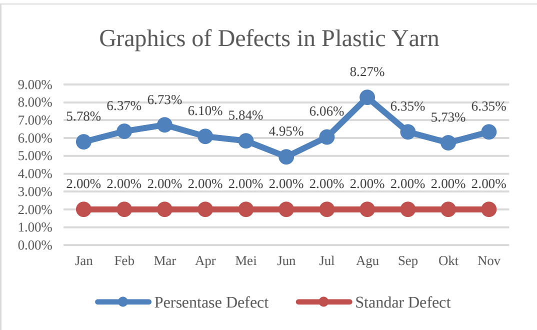

Figure 1. Plastic thread production defect

Based on Figure 1, the average thread defect is 6.23%, exceeding the standard defect limit of 2.00% set by the company. This fact shows that the production process is carried out by PT. XYZ is not optimal. To overcome this problem, research is needed to identify priority failures through the Failure

Mode and Effect Analysis (FMEA) process. [6]. This effort aims to identify risks that could cause significant failure proactively. [7]. Using FMEA, companies can systematically identify possible causes and consequences of failure. [8]. The Kaizen approach facilitates PT XYZ in continuing to make continuous improvements through small improvements in their production processes. [9]. Adopting a kaizen approach by considering 5W+1H (What, Why, Where, When, Who, How), PT. XYZ can thoroughly analyse the risk of failure and propose effective improvements to prevent it [10].

Research Methods

The data needed to design a failure risk analysis using the FMEA method and the Kaizen approach consists of secondary and primary data. [11]. Secondary data was obtained through indirect observation using historical records from the QC department from January to November 2023. Check sheet data includes quantitative information regarding production quantities and types of product defects, while primary data is obtained through direct observation, unstructured interviews with related parties, and questionnaire assessments of related respondents [12].

Primary data was collected through direct observation and unstructured interviews with related parties to understand better the phenomenon being studied. [13]. The sources used are the production section head, quality control section head, and mechanical section head; unstructured interview data involving mechanical engineering operators, bobbin thread operators, and machine mechanics to obtain comprehensive information regarding the factors causing defects. This qualitative data includes factors causing defects, risk of failure, and impact of failure. Questionnaire data was collected from 10 respondents who had worked for five years and had an in-depth understanding of the yarn extrusion process. [14].

This research processes data using quality control tools such as Pareto and fishbone diagrams.[15]. The Pareto diagram is prepared by arranging data based on the defect severity order, from the highest to the lowest, obtained from the check sheet results. [16]. Pareto diagrams and fishbone diagrams are connected in explaining cause-and-effect relationships. The Pareto principle shows that 20% of the types of defects may cause 80% of the types of defects that occur. [17]. The results of the Pareto diagram can make it easier to determine the steps in selecting the type of defect that will be analysed further on the fishbone diagram. The fishbone diagram was created based on qualitative data regarding the causes and consequences of product defects obtained from interviews with related parties. The results of the fishbone diagram analysis will be further processed using the FMEA method to evaluate failure modes at each stage of the production process. [18].

Failure Mode and Analysis (FMEA) aims to identify failure modes with the highest Risk Priority Number (RPN) values. Respondents conduct the assessment using a rating scale from 1 (one) to 10 (ten). The assessment parameters used include the severity, frequency of occurrence, and detectability of the failure modes identified in the production process. [19], [20]. The severity rating increases with the severity of the failure mode; the higher the rating, the higher the level of severity that occurs. Rating events increase as the potential cause occurs more frequently; the higher the rating, the more often the potential cause occurs. The detection rating increases with the difficulty of detecting the cause of the failure mode; the higher the rating, the more difficult it is to detect the cause. [21]. The average results of respondents' assessments for each failure mode will be multiplied to determine the Risk Priority Number (RPN) value[22], [23].

The RPN is arranged from highest to lowest value to determine appropriate improvement steps. The failure mode with the highest RPN is the top priority for repair. [24]. Proposed improvements will be implemented using the Kaizen method approach. This approach will address key questions about what needs to be improved (what), why the improvement is needed (why), where the improvement will be implemented (where), when the progress will be made (when), who is responsible for its implementation (who) , and how improvements will be made (how) [25].

Results and Discussion

Check Sheet

The data used is historical data from inspection sheets from January 2023 to November 2023. This data includes production data, the number of defects, and the number of types of defects in plastic threads. The following is the PT XYZ check sheet data:

Table 1 Plastic thread check sheet data for the period January 2023 – November 2023

Month (2023)	Sum production	Kind *Defect*					Sum *defect*	Propors *defect*
		Thread Spotted	Thread Break	Thread Serrated	Diameter does not Match	Color Striped		
Jan	640	13	6	5	9	4	37	5,78%
Feb	612	21	5	2	8	3	39	6,37%
Mar	654	18	5	5	9	7	44	6,73%
Apr	607	14	6	3	8	6	37	6,10%
Mei	599	17	4	4	7	3	35	5,84%
Jun	586	10	5	5	6	3	29	4,95%
Jul	644	16	7	2	9	5	39	6,06%
Agu	532	24	10	3	5	2	44	8,27%
Sep	630	16	8	2	9	5	40	6,35%
Oct	628	17	6	3	6	4	36	5,73%
Nov	630	12	10	5	11	2	40	6,35%
Total	6762	178	72	39	87	44	420	6,21%
Average	614,73	16,18	6,55	3,55	7,91	4,00	38,18	6,23%

Diagram Pareto

This diagram helps prioritize the types of problems or defects that occur in the production process. The Pareto diagram data processing process uses data on defect types and the number of defects from the inspection sheet from January 2023 to November 2023. The data is sorted from the highest to the lowest number of defects, then the percentage and accumulative value of all existing defects is calculated. The following are the results of tables and graphs for compiling a Pareto diagram:

Table 2 Pareto diagram data results

No	Sum *Defect*	Sum *Defect*	Percentage	Accumulation
1	Thread Spotted	178	42,38%	42,38%
2	Diameter Does Not Match	87	20,71%	63,10%
3	Thread Break	72	17,14%	80,24%
4	Color Striped	44	10,48%	90,71%
5	Thread Serated	39	9,29%	100,00%
	Total	**420**	**100,00%**	

Based on Table 2 above, a Pareto diagram can be drawn using Microsoft Excel software to determine the level of defects that are the main priority for repair. The following is a Pareto diagram of the types of defects in plastic threads:

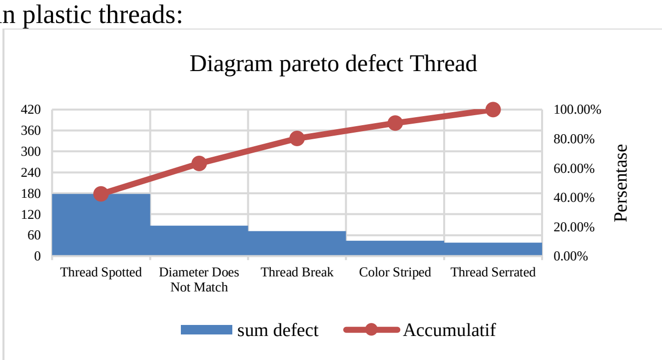

Figure 2. Pareto diagram on types of thread defects

Based on Figure 2 above, the highest type of defect was found in spotted thread defects with a percentage value of 42.38%. The implementation of the Pareto diagram continues with the fishbone diagram, looking for factors that cause spot thread defects to reduce the number of defects that occur.

Diagram Fish Bone

The fishbone diagram was created to identify the factors that cause defects in yarn production. Fishbone diagram analysis in determining causal factors uses primary data from observations and interviews with respondents related to the production process. The following are the results of processing the fishbone diagram data:

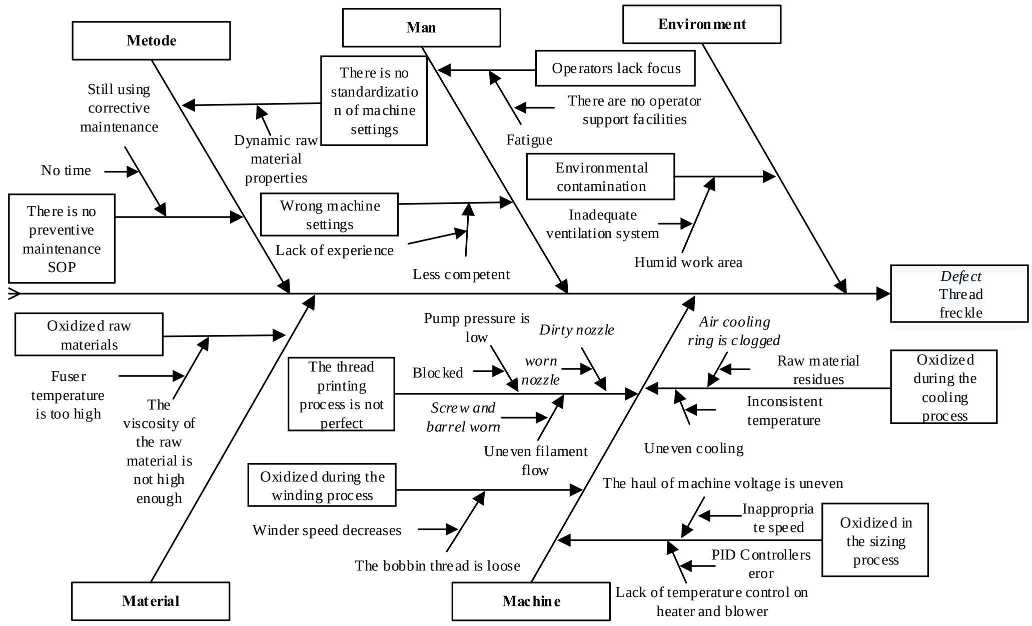

Figure 3. Spotted thread defect fishbone diagram

Based on Figure 3 above, 5 (five) factors cause spot thread defects: method, human, environmental, material, and machine factors. The following is an analysis of each causal factor:

1. Method

The method factors shown in the fishbone diagram occur because the results of each raw material test are dynamic. There is no extruder machine component settings standardization, only a formula for calculating the settings. The operator must formulate the right settings so that the product produced complies with the quality standards set by the company. Another factor is the lack of time to carry out preventive maintenance. The condition of the machine is that it works 24 hours a day, so the company uses corrective maintenance methods when machine parts are indicated by significant process failures/production defects.

2. Human

The human factor in the fishbone diagram occurs due to the operator's lack of competence in setting up the machine. This is based on a lack of experience in solving the problems that can lead to wrong settings. Another factor is operators not being focused while working due to poor physical conditions, which disrupts the production process. This condition cannot be avoided because operators have no supporting facilities when working. Still, it is hoped that every operator must maintain physical condition when performing their duties.

3. Environment

The environmental factors shown in the fishbone diagram occur as a result of the work area being damp due to inadequate air ventilation, causing the raw material to be contaminated by air and causing spot defects in the thread extrusion results.

4. Materials

The material factor shown in the fishbone diagram occurs due to the raw material settling for a long time in the thread extrusion line and the low viscosity of the raw material because the melting temperature is too high, which can cause the raw material to oxidize.

5. Machine

The machine factor shown in the fishbone diagram occurs due to uneven cooling and imperfect thread printing processes. The temperature of the cooling process carried out by the AC tank/water cooling tank is inconsistent because the old machine cannot maintain the coolness of the AC tank water.

The clogged ring water also causes the cooling process, so the extrusion results' cooling process is uneven.

The thread printing process is imperfect because the pump pressure is too low, which can cause the thread to have hollow defects. After all, it is not strong enough to remove air bubbles. A dirty nozzle surface occurs because residual raw materials settle on the surface of the worn nozzle. Screw and barrel wear can result in uneven flow of plastic filament, causing the formation of oxidation and air voids in the extruded filament.

Lack of proper temperature control on the heater and blower can result in thermally and structurally unbalanced threads, leading to air void defects. The pulling speed of the haul of a machine is too high or too low and can cause uneven thread tension, resulting in air bubbles in the thread filament. Inconsistent winding speed can result in a too-loose thread, so empty spaces can form in the spool.

Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis (FMEA) on spot yarn defects aims to assess the failure modes identified in the yarn production process. The identified failure modes will be evaluated by respondents based on the criteria of severity, occurrence, and detectability. The author used 10 (ten) respondents with the requirements of working for 5 (five) years, understanding the entire production process flow, and understanding machine components. The results of the respondent's assessment are calculated using the average formula for each failure mode. The following are the results of the failure mode assessment:

Table 3 Assessment of failure modes of spotted thread defects

Failure Type	***Process***	***Code***	***Potential Impact***	**S**	***Potential Causes***	**O**	***Detection Mode***	**D**
*Defect*s potted thread	(*Smelting Plastic*)	A1	*Visccositas* raw materials are not high enough	5	Melting temperature too high	2,6	*Test viscometer* and machine configuration settings	2,8
	(*Molding*)	B1	Pump pressure is low	8,7	Blockage in the inlet	3,4	Direct visual inspection	6
		B2	Uneven filament flow	8,3	Worn screw and barrel	2,5	Direct visual inspection and denier test	5,7
		B3	*Nozzle* Dirty	8,4	The nozzle surface is worn	2,4	Direct visual inspection	5,1
	(*Cooling*)	C1	Air cooling ring is clogged	3,3	Raw material residues	3,1	Direct visual inspection	4,7
		C2	Uneven cooling	3,4	Inconsistent coolant temperature	3,2	Temperature sensor and engine configuration settings	1
	(*Sizening*)	D1	Lack of temperature control on heater and blower	5,6	PID *controllers' error*	1,6	Temperature sensor and engine configuration settings	1
		D2	The haul of machine voltage is uneven	5,4	Inappropriate speed	2,3	Direct visual inspection, machine configuration settings, and autograph test	2,5
	(*Winding*)	E1	The result of winding the thread on the bobbin is loose	5,5	Winder speed is inconsistent	4	Direct visual inspection and machine configuration settings	2,6

Based on Table 3 above, FMEA prioritizes failure mode analysis during production without depending on failure in a particular process. FMEA considers factors such as humans, machines, methods, materials, measurements, and the environment. Each of these elements has its own sub-elements that can work independently, together, or even interact with each other to produce failure. Once the severity, occurrence, and detectability values have been obtained, RPN values can be calculated for each failure mode. Each failure mode's average severity, occurrence, and detectability values are multiplied to determine the RPN value. The failure mode with the largest RPN value is the priority for corrective action. The following is a table of risk priority numbers (RPN) for each failure mode:

Table 4 RPN failure mode

Number	*Code*	*Failure Mode*	*RPN*
1	B1	Pump pressure is low	177,48
2	B2	Uneven filament flow	118,28
3	B3	*Nozzle* Dirty	102,82
4	E1	The result of winding the thread on the bobbin is loose	57,20
5	C1	The air-cooling ring is clogged	48,08
6	A1	The visccosity of the raw material is not high enough	36,40
7	D2	Uneven cooling	31,05
8	C2	Uneven cooling	10,88
9	D1	Lack of temperature control on heater and blower	8,96

Based on Table 4 above, 9 (nine) types of failure modes cause spot thread defects in the production process. The biggest problem of freckle thread defects is caused by the failure mode of low pump pressure because it has an RPN value of 177.48 with a severity value of 8.7. Because of this failure, the thread filament printing process is not strong enough to remove air bubbles, which can cause freckle-type defects and must be repaired immediately. Improvements to this process are carried out based on the causes of failure, which have been analysed using the Failure Mode and Effect Analysis (FMEA) method so that the problems that occur are known for repairs.

Proposed Improvements Using the Kaizen Approach

Improvement proposals using the Kaizen 5W+1H approach is used to determine the relationship between the causes and effects of defects and find solutions by describing the best decisions for implementing appropriate actions. Proposed improvements are analysed by making direct observations and conducting unstructured interviews with the head of the production section, head of the quality control section, head of the mechanical section, technical operators, bobbin thread operators, machine mechanics, and other parties. The following are proposed improvements that can correct the failure mode:

Table 5 Proposed 5W+1H improvements

No	Factor	What	Why	Where	When	Who	How
1	Blockage in the inlet	Installing pressure transducers	So that the filament pressure flowing through the cylinder matches the pump's capabilities	Cylinder and nozzle in the molding process	This is done before starting the production process	Technical operator in charge of the thread extrusion section	Pressure transducers are installed between the cylinder and the nozzle and then set so that the pump pressure is controlled
2	Too many filaments	Provide warnings related to operational standards for raw	So that the yarn extrusion process complies with the	In the Hopper, the filament container is placed	Done before carrying out the process of filling raw materials	Head of the yarn production planning division	Conduct briefings to operators to observe

		material extraction	specified quality standard specifications	before entering the extrusion process		and operator	hopper capacity
3	There is no downtime for preventive maintenance	Develop and implement preventive maintenance consistently	So that the machines used for production do not lose their proper lifetime	Plastic thread production extruder machine	Carried out according to a predetermined schedule before the machine experiences downtime	Mechanic on duty	Create and implement preventive maintenance SOP according to machine downtime data.
4	There are no supporting facilities for extruder machine operators	Provide supporting facilities in the form of chairs	So that operators do not quickly experience fatigue in carrying out their duties	Extruder machine area production floor	Carried out during the production process	Engineering operator and bobbin operator	Providing and placing facilities in the form of ergonomic chairs so that operators do not get tired

Based on Table 5 above, repairs are carried out by consistently organising and carrying out preventive maintenance activities on each machine part not to lose the machine's proper lifetime and not hamper the production process if damage occurs because the machine is poorly maintained. The pump pressure control is proposed by installing a pressure transducer between the cylinder and nozzle so that the filament flowing in the moulding process matches the pump pressure capability.

Providing a warning regarding overload hopper capacity is also given to adjust the filament flowing during the extrusion process. This proposal is carried out by briefing the operator to pay more attention to the hopper capacity before filling raw materials into the extruder machine. Providing supporting facilities to operators in the extruder machine area is also necessary so that operators do not quickly experience fatigue in carrying out their duties.

Conclusion

Analysis of the risk of failure using the FMEA method and the Kaizen Approach in the plastic thread production process at PT XYZ Gresik can mean that the production process is not optimal. This is proven by the check sheet data obtained from January 2023 to November 2023, which has a defect proportion level of 6.23%. The defect proportion level exceeds the standard defect limit of 2% set by the company. There are 5 (five) types of defects identified. Spotted thread defects are a priority for repairing failure modes because they account for 42.38%.

The risk of failure in the spot thread defect problem is caused by the pump pressure failure mode is less because it has an RPN of 177.48 with a severity value of 8.7. This failure mode causes the thread filament printing process not to be strong enough to remove air bubbles, which can cause spot thread defects and must be repaired immediately.

The company's proposed improvement is to install a pressure control device and provide a warning when the filament in the moulding component is overloaded so that the pump can easily press the flowing filament. Develop and consistently perform preventive maintenance activities on each machine part to not lose the machine's lifetime. They provide supporting facilities to operators so they do not quickly experience fatigue.

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