Risks potency analysis of flakes machine in banana flakes production process using failure modes and effects analysis (FMEA)

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Abstract: Banana flakes are foods that can be eaten daily and benefit the body. This product is made from bananas containing lots of prebiotics and other nutrients. Research on processing breakfast cereals, especially flakes, is still rarely performed. Banana flakes are processed by mixing the main ingredients and supporting materials using a mixer, dough sheeting using a dough sheeter, half-baked using an oven, cutting using scissors manually, and roasting until cooked. The cutting process is a bottleneck in the banana flakes production process because these steps are carried out manually. Therefore, an automatic banana flakes production machine was developed. During the production process, the machine flakes will indeed have a risk of failure. An analysis of potential failure is carried out to prevent the risk of loss from disrupting the production process because the flakes machine is still being developed, so there is no specific failure analysis for this machine. This research aims to analyze the potential risk of failure using failure modes and effects analysis (FMEA) for the developed banana flakes machine. FMEA is an analytical technique for determining and classifying common failures and should be considered in flakes machines. An appropriate severity, occurrence, and detection assessment results in a risk priority number (RPN) score to take preventative measures. Pulley and belt slips that occur in the transmission component of the conveyor have the highest RPN score of 168. Six potential failure modes have an RPN value above 100. These should be concerned with preventing failure, reducing the severity, and reducing risk by recommended corrective action.

Keywords: failure modes and effect analysis (FMEA), flakes machine, banana flakes, risk priority number (RPN)

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1 Introduction

Banana flakes are processed food products made from ripe banana flour, an alternative for breakfast. Banana flakes contain prebiotics from bananas (Surahman et al., 2019). Banana flakes are suitable for human digestion, as seen in Figure 1. Banana flakes are processed through several stages: mixing the main ingredients and supporting materials until homogeneous using a mixer, sheeting the dough using a dough sheet machine, and roasting half-cooked utilizing an oven. Furthermore, banana flakes were cut into squares of 20 mm × 20 mm using scissors manually and then baked again until cooked. The constraints experienced during the process were caused by the soft and sticky nature of the dough, which required several steps to be carried out manually. Research on the processing of cereals for breakfast, especially products in the form of flakes, is rarely carried out (Ratnawati and Afifah, 2017).

Thus, a particular machine for processing flakes made from ripe banana flour has not yet been developed.

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A flakes machine has been designed for the banana flakes production process to solve this problem, as shown in Figure 2. Hopefully, this machine will solve the manual cutting problem. In detail, this machine shapes and cuts banana flakes dough to simplify and speed up the production process so that production speed can be increased. In the method of operating this machine, potential failures can occur, disrupting the production process. For this reason, analyzing potential risks that will reduce production delays, injuries, or work accidents is necessary. This analysis is very important for every production machine, especially the flakes.

Figure 1 Banana flakes

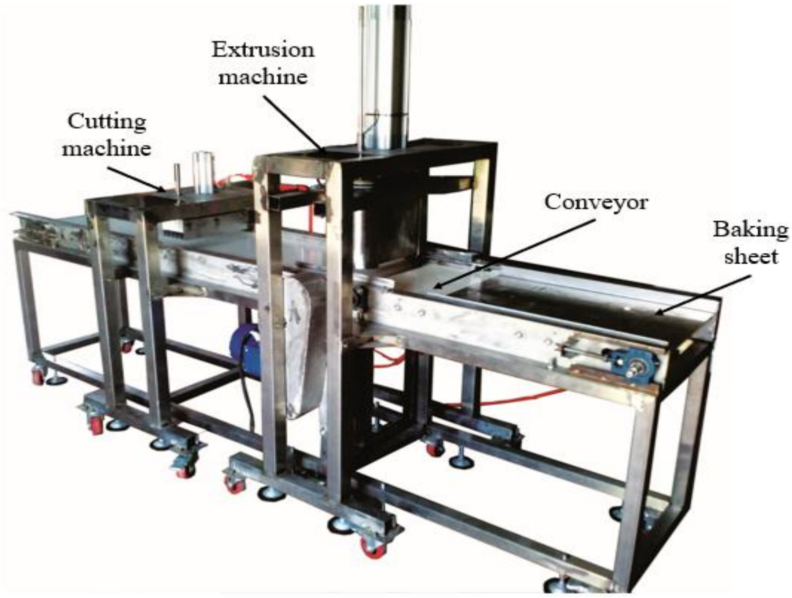

Figure 2 Flakes machine

Failure modes and effect analysis (FMEA) is a technique in analyzing failures commonly used in engineering projects (Feili et al., 2013). The failure mode defined in FMEA is the failure that can produce something undesirable, such as a production process that is stunted, injured, or accident (Ebrahimipour et al., 2010). Failure in machines and processes is always the point of organizational difficulty (Boral et al., 2019). So that is something vital. FMEA is very helpful in research activities and is widely used to analyze the failure of various equipment or machines. For example, FMEA is used by (Singh et al., 2019) to diagnose failures in distribution transformers, geothermal power plants (Feili et al., 2013), and offshore wind turbine systems (Scheu et al., 2019). There are also reviewed journals that use FMEA in analyzing failures of each piece of equipment (Liu et al., 2013). From the process side, FMEA is used by Chen and Wu (2015) in building prevention mechanisms for municipal solid waste (MSW) life cycles. In the food industry, FMEA was applied in conjunction with cause-and-effect analysis for the risk assessment of octopus processing (Octopus

Vulgaris) (Arvanitoyannis and Varzakas, 2009). FMEA can also be applied to the processing and packaging of salmon (Arvanitoyannis and Varzakas, 2008). FMEA is considered very suitable to be used in identifying potential failures that occur in flakes machines. By using this method, several possibilities and potential losses and problems that arise in the flakes machine can be avoided or prevented so that the banana flakes production process can run smoothly. Applying the FMEA model in confectionary manufacturing can also improve the safety and quality of the final product (Ozilgen, 2012).

2 Materials and methods

2.1 Flakes machine information

This machine consists of four main parts: the extrusion machine, cutting machine, conveyor, and control panel. Figure 3 shows the block diagram of a flakes machine system consisting of the main machine parts. The first part of the flakes machine, the extrusion machine, makes the dough into thin sheets with a maximum thickness of 1.5 mm. The size of the die hole on the extrusion machine is 20 mm x 1.5 mm, a total of 11 die holes made elongated and parallel. The function is made lengthwise and parallels so that it does not stick between one sheet with another.

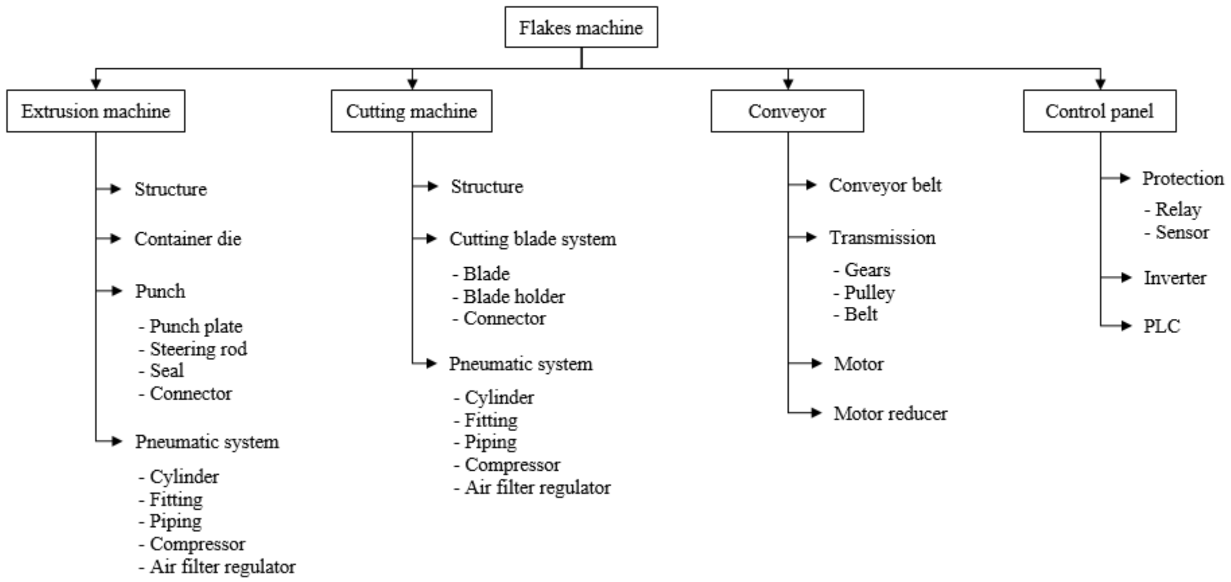

Figure 3 Block diagram of flakes machine

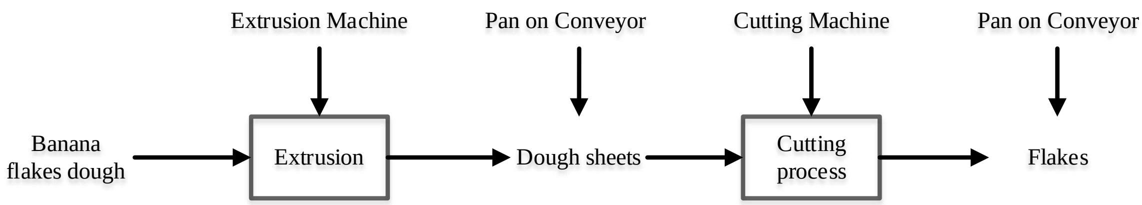

Figure 4 Block diagram of the banana flakes production process using a flakes machine

Extrusion machines are made using the extrusion system approach. Extrusion techniques have been used extensively in the food industry because they have various advantages. Better product quality, mechanical properties, and the extruded products' strength are the extrusion process's advantages (Das et al., 2014). Besides, extrusion techniques have high productivity, varied product shapes, and are very economical for producing new products (Harper, 1981; Maskan and Altan, 2012). The extrusion technique is a technique used to move energy from the source to the dough. Its function is to form metal or nonmetal materials with the press method (DA, 2005). The main components of extrusion machines consist of a punch, container, and die (Li et al., 2014; Seki et al., 2017).

The cutting machine cuts the dough sheet transversely after exiting the extrusion machine so that the dough will measure 20 mm × 20 mm × 1.5 mm. Cutting techniques of steel, sheet metal, or food dough have forces couple used for cutting (Singh et al., 2016). The force will work simultaneously, in opposite directions, with a relatively small distance called shear. In dough cutting, there will be an area called the shearing area (Kalhori, 2001). A conveyor is used to carry the baking pan to the extrusion machine and cutting machine. The flakes machine process can be seen in the banana flakes production process's block diagram using a flakes machine (Figure 4).

2.2 Flakes machine failure analysis

2.2.1 Failure modes and effects analysis (FMEA)

FMEA is a systematic method used to analyze and rank risks and failures (both those that have occurred and those that have the potential) of a machine, find out the main priorities in repairing, evaluating problems, and providing solutions to overcome them (KW, 2004; Barends et al., 2012; Feili et al., 2013). FMEA is widely used as a reliability tool to recognize possible failures before they occur to reduce risk (Puente et al., 2002; Narayanagounder and Gurusami, 2009; Feili et al., 2013; Singh et al., 2019). Identifying failure modes is how the failure is observed, illustrates how it occurred, and its impact on machine operation (Singh et al., 2019). Several criteria are considered in carrying out FMEA, among others (Jensen et al., 2012); risk identified by the system or concept of FMEA, the potential for safety issues, new technology, new applications of existing technology, history of significant field problems, the potential for essential regulation issues, mission-critical applications, and supplier capability. One crucial step in applying the FMEA method is breaking down a system into individual components (Figure 3).

Table 1 The severity of a failure mode (Chang and Sun, 2009; Liu et al., 2013)

Effect	Criteria: severity of the effect	Rank
Hazardous	Failure is hazardous and occurs without warning. It suspends the operation of the system and/or involves noncompliance with government regulations	10
Serious	Failure involves hazardous outcomes and/or noncompliance with government regulations or standards	9
Extreme	The product is inoperable with a loss of primary function. The system is inoperable	8
Major	Product performance is severely affected but functions. The system may not operate	7
Significant	Product performance is degraded. Comfort or convince functions may not operate	6
Moderate	Moderate effect on product performance. The product requires repair	5
Low	Minor effect on product performance. The product does not require repair	4
Minor	Negligible impact on product or system performance	3
Very minor	less effect on product or system performance	2
None	No effect	1

Table 2 Occurrence of failure mode (Mode, 1995)

Probability of failure	Possible failure rates	Rank
Very high: failure is almost inevitable	≥ 1 in 2	10
	1 in 3	9
High: Repeated failures	1 in 8	8
	1 in 20	7
Moderate: Occasional failures	1 in 80	6
	1 in 400	5
	1 in 2000	4
Low: Relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	≤ 1 in 1,500,000	1

Table 3 The severity of a failure mode (Chang and Cheng, 2010; Liu et al., 2013)

Detection	Criteria: the likelihood of detection by the design control	Rank
Absolute uncertainty	Design control does not detect a potential cause of the failure or subsequent failure mode, or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause of the failure or subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause of the failure or subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause of the failure or subsequent failure mode	7
Low	Low chance the design control will detect a potential cause of the failure or subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause of the failure or subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause of the failure or subsequent failure mode	4
High	High chance the design control will detect a potential cause of the failure or subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause of the failure or subsequent failure mode	2
Almost certain	Design control will almost certainly detect a potential cause of the failure or subsequent failure mode	1

The FMEA stage begins by observing the details of the design, observing the process and workflow of the machine, making a block diagram of equipment components and workflows, analyzing the potential and risks that can cause the failure of each element, analyzing the effects, causes, and how to detect them (Mode, 1995). FMEA is applied to determine priority actions by considering the degrees of severity (S), occurrence (O), and detection (D). The Risk Priority Number (RPN) is then calculated using the following formula (Puente et al., 2002; Chen and Wu, 2015) :

$$RPN = S \times O \times D \quad (1)$$

The highest RPN must be focused, and the most vulnerable to failure must be analyzed seriously to reduce the risk of failure (Mariajayaprakash and Senthilvelan, 2013). Severity is the measure of the severity of the potential effect of the failure. Rate 10 is allocated to the failure resulting in significant damage given in Table 1. Occurrence is the measure of the likelihood of failure, described qualitatively in Table 2. Detection is the measure of the probability that the problem will be detected, given in Table 3 (Singh et al., 2019).

The main focus for priority components is on failure modes with an RPN score exceeding 100, which is generally accepted as a threshold (Ho and Liao, 2011; Chen and Wu, 2015). These modes are classified as the top priority and are considered essential factors in the final stages. FMEA for the flakes machine is performed to analyze the potential risk of each machine component, analyze the likely failure mode, the possible effect of failure, the possible cause of failure, control design, recommended action, and make an RPN score.

2.2.2 FMEA procedure for flakes machine

Analysis procedures must be made to determine potential failures and risks in flake machines. Starting from reviewing the concept of design, understanding the function, and understanding the workings of the machine is the initial analysis that must be done—identifying systems, identifying existing components, and analyzing the critical points for each element. The potential failures are poured into the FMEA worksheet and studied in the possibility of severity, occurrence, and detection to get an RPN score. The final stage in FMEA is to provide an analysis of recommendations used for the prevention and maintenance of flake machines. Figure 5 shows the FMEA procedure for the flakes machine.

3 Result and discussion

Analysis of potential risks in flake machines using FMEA, there are 21 possible failure modes and 21 RPN divided into four items. The four items are extrusion machines, as in Table 4; Cutting machines, as in Table 5; conveyors, as in Table 6; and control panels, as in Table 7. The extrusion machine consists of four main components. As for the cutting machine, conveyor, and control panel, each consists of three main parts. The result is that six potential failure modes have an RPN score above 100.

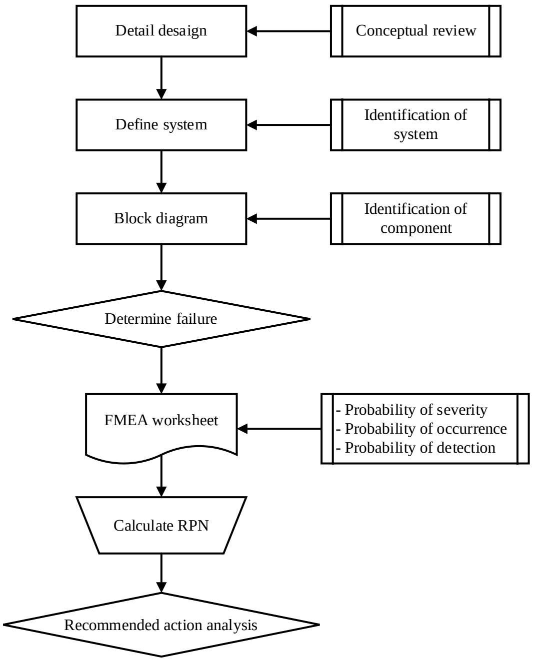

Figure 5 FMEA procedure for flakes machine

Table 4 FMEA of extrusion machine

Component	Function	Potential failure mode	Potential effect(s) of failure	S	Potential causes(s) of failure	O	Current design controls (Prevention)	Current design controls (Detection)	D	RPN	Recommended action
Structure	Extrusion machine support	Fatigue crack	Crack welding	5	Repetitive load during the extrusion process	2	Use welding standards	Check all welding connections	7	70	Repair
Container die	Dough container and extrusion die	Fatigue cracks occur due to critical stress	The container die is damaged	8	Repetitive load during the extrusion process	2	Loading does not exceed the capacity	Check the condition of the container die	7	112	Replace
Punch	Pressing the banana flakes dough	The plate punch is bent	The punch plate is deformed	2	Repetitive load during the extrusion process	5	Redesign punch plate. Loading does not exceed the capacity	Check and see the condition of the punch plate	2	20	Repair
		The punch seal is broken	causing the dough to have a backflow	7	Friction	8	Use food-grade lubricants	Visually inspect before processing	2	112	replace seal
		Connector is crack	punch cannot work	6	Misalignment	2	Tighten the bolt	Check before processing	8	96	Repair and replace
Pneumatic system	Actuator	The cylinder rod is bent	Actuator cannot work optimally	7	Repetitive load during the extrusion process	2	Loading does not exceed the capacity	Check before processing	6	84	Replace the pneumatic cylinder
		Leaking connectors	reduced air to the actuator	5	Installation of fittings that are not tight, broken fittings	6	Tighten the fittings	Check before processing	1	30	Add seal tip, replace fittings
		The air filter regulator is broken	Air filter regulator cannot filter water and oil	5	Air filter regulator filled with water and oil	2	The air filter regulator is not full	Check before processing	1	10	Drain or replace the air regulator filter

Table 5 FMEA of cutting machine

Component	Function	Potential failure mode	Potential effect(s) of failure	S	Potential causes(s) of failure	O	Current design controls (Prevention)	Current design controls (Detection)	D	RPN	Recommended action
Structure	Cutting machine support	Fatigue crack occurs in the welding system between the actuator mounting plate and the frame	Crack welding	5	Repetitive load during the extrusion process	2	Loading does not exceed the capacity	Check all welding connections in the structure before processing	7	70	Repair
Cutting blade system	Cut the transverse dough position	Uneven blade mounting	The blade cannot cut; the edge is bent	5	human error	6	Make sure the blade is flat	Check the cutting blade system and do a load-testing machine before the process	4	120	Install the blade properly
Pneumatic system	Actuator	The cylinder rod is bent	Actuator cannot work optimally	7	Repetitive load during the extrusion process	2	Loading does not exceed the capacity	Check before processing	6	84	Replace the pneumatic cylinder
		Oil leakage on the compressor motor	The compressor quickly heats, oil decreased	6	Seal is damaged, the oil is contaminated, oil is reduced	2	Make sure the oil input seal and bolt are firmly attached	Check the condition of the motor, seal, and oil level	2	24	Replace seal, add or replace oil

Table 6 FMEA of conveyor

Component	Function	Potential failure mode	Potential effect(s) of failure	S	Potential causes(s) of failure	O	Current design controls (Prevention)	Current design controls (Detection)	D	RPN	Recommended action
Belt conveyor	Bring a baking pan	The belt conveyor is broken	The conveyor cannot carry the baking pan, and the production process stops	7	Installation of conveyor belts is too tight, exposed to cutting blades	2	Adjust the belt conveyor tightness, adjust the cutting distance according to the length of the baking pan	Check before processing	4	56	Replace
Transmission	Power transfer	Wear gears	Slips	7	Continuous friction	2	Adjust the pitch distance between the two gears	Check the gears before processing	4	56	Replace
		Belt broke	The motor cannot move the conveyor	7	The conveyor belt installation is too tight	2	Adjust belt tension	Check the belt before processing	4	56	Replace
		Pulleys and belt slips	Slips	7	Deformation	6	Adjust belt tension	Check before processing	4	168	Replace
Motor	Move the conveyor	Oil leakage, high temperature	The compressor quickly heats, the compressor cannot work optimally	6	Seal is damaged, oil is contaminated, oil is reduced	2	Make sure the oil input seal and bolt are firmly attached	Check the condition of the motor, seal, and oil level	2	24	Replace seal, add or replace oil

Table 7 FMEA of the control panel

Component	Function	Potential failure mode	Potential effect(s) of failure	S	Potential causes(s) of failure	O	Current design controls (Prevention)	Current design controls (Detection)	D	RPN	Recommended action
Protection	Command and protect the control system	Disconnected sensor	There is no synchronization between the extrusion machine, cutting machine, conveyor, and baking pan	8	The sensor is broken, and the cable is broken	5	Set the sensor distance to the pan	Check the sensor and do a load-testing machine before the process	3	120	Replace
		Relay is broken	Stopped system	7	Electric current increases	3	Use power supply	Check before processing	4	84	Replace
Inverter	Motor speed control	Inverter set error	Motor speed is too fast or too slow	5	human error	3	Do not change the inverter settings	Check and do a load-testing machine before the process	2	30	Set the motor speed
PLC	Sequential process control	Disconnected	Stopped system	8	The cable is damaged , and the port is damaged	2	Replace the cable and port	Check and do a load-testing machine before the process	7	112	Replace

Six potential failure modes exceed the RPN 100 score. Those are pulley and belt slips, uneven blade mounting, the disconnected sensor of the control panel, the disconnected PLC of the control panel, the broken punch seal, and the fatigue cracks. The pulley and belt slips that occur in the transmission component of the conveyor have the highest RPN score of 168

Besides, four potential failure modes approach the RPN 100 score or an RPN score above 80. Which also has the potential for failure and the potential to be a priority. The four potential failure modes, i.e., cracking connector, bending cylinder rod, curving cylinder rod, and error setting of the inverter. Ten potential failure modes should be of particular concern to flakes machine users to prevent failures, as shown in Figure 6.

The most potential failures based on RPN scores are found in the extrusion machine by 34.7% because the potential failure mode in extrusion machines is more than in other machine items. Also, the extrusion machine has four potential failure modes on the top 10 RPNs. Furthermore, successive potential failures were found in the conveyor 23.4%, control panel 22.5%, and cutting machine 19.4%, as shown in Figure 7. The values of S cause the high RPN score for potential failure mode, O, and D, which are relatively balanced or evenly distributed. As in the pulley and belt slips that occur in the transmission components on the conveyor and uneven blade mounting on the cutting blade system on the cutting machine shown in Figure 8. Nothing dominated S, O, and D for the two significant RPN scores.

Preventing failures on the flakes machine needs an understanding of the design controls and actions in Table 4 of each potential failure that can occur, especially for the top 10 RPNs. Check before the flakes machine is applied to detect the most common failures. Checking can be focused on RPN scores that exceed 100, generally accepted as a threshold (Chen and Wu, 2015), or on the top 10 RPNs. Maintenance can be carried out on all components, referring to the current design control (prevention) in Table 4-7, which aims to prevent more widespread failures. Recommended action in general, if there are indications of failure, namely repairs and even must be replaced.

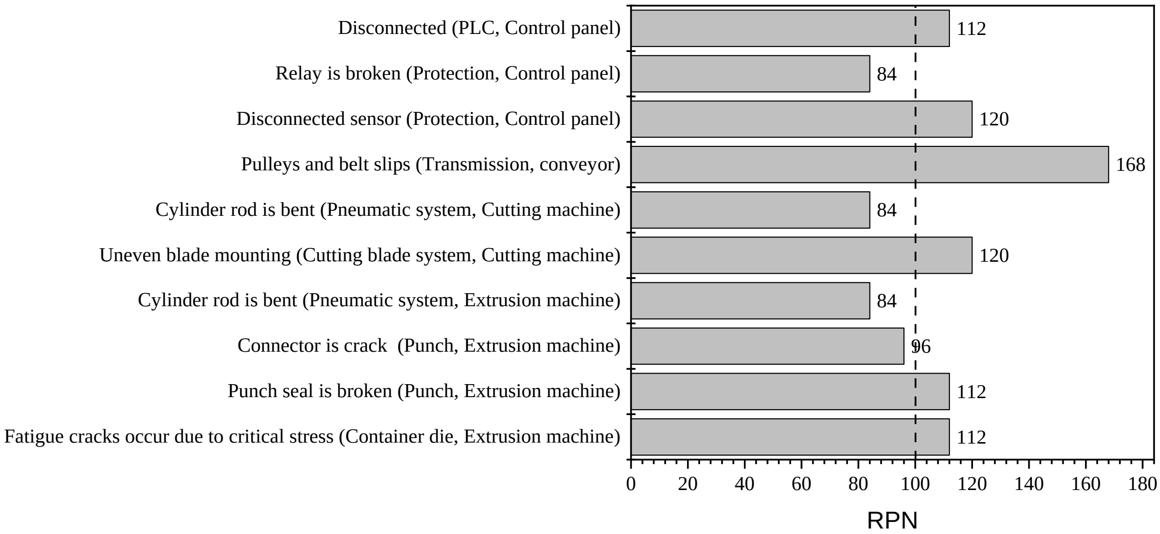

Figure 6 Top 10 RPNs

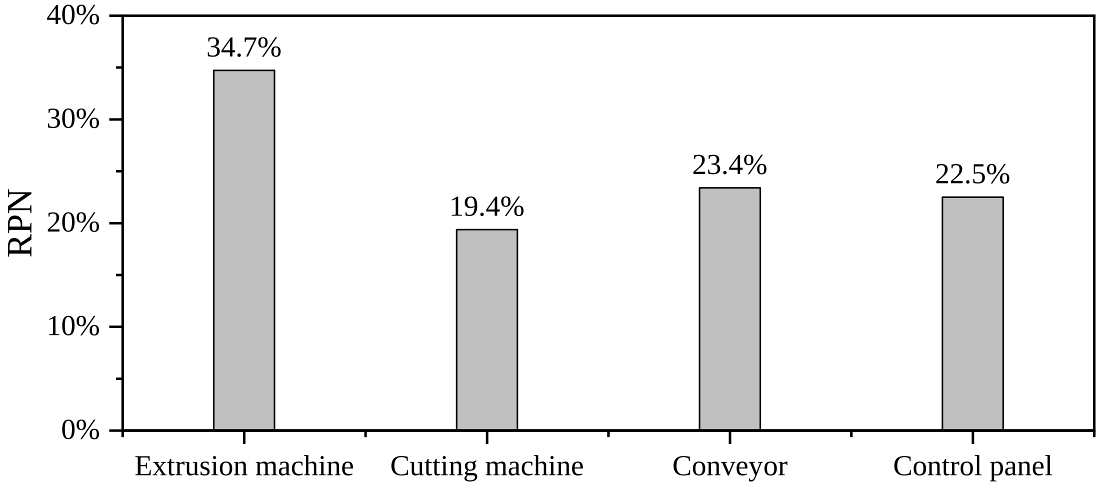

Figure 7 The percentage composition of the total RPN of each machine item from the flakes machine

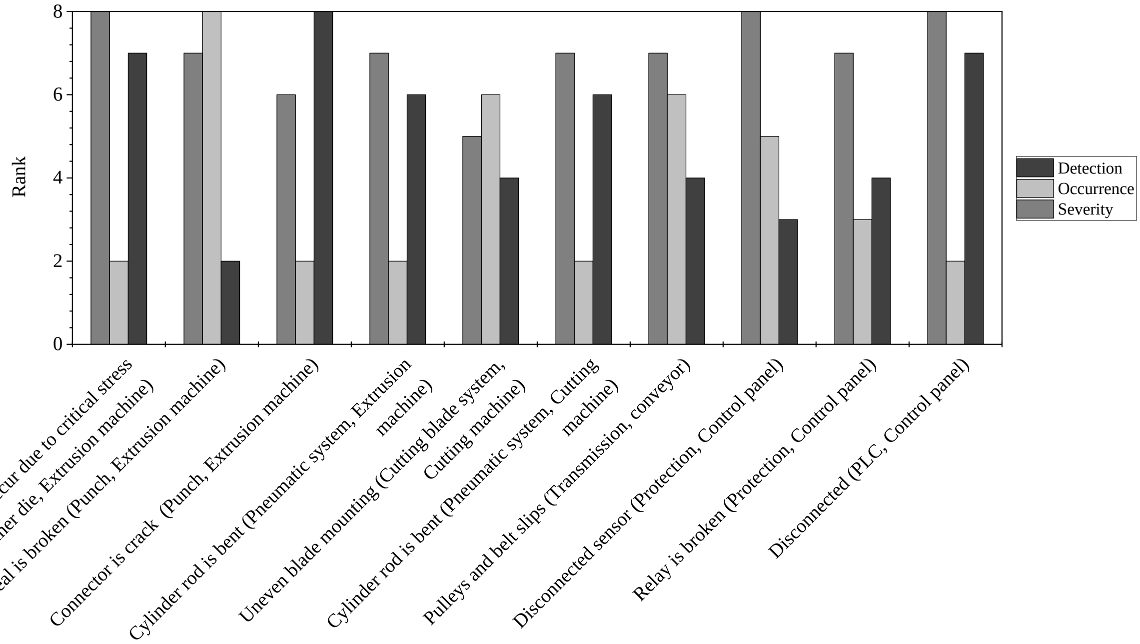

Figure 8 Severity, occurrence, and detection of the failure modes with top 10 RPNs

4 Conclusion

Identifying, controlling, and reducing the potential for failure on the flakes machine is very important because the flakes machine is a new technological innovation, and this technology will be used for the banana flakes production process. FMEA is focused on components of flakes machines that are considered to have potential failures and risk the obstruction of the production process. This failure mode must receive special attention and be a standard operational procedure reference. Six possible failure modes score RPN above 100, and four potential failure modes approach RPN 100 scores. Preventive maintenance is needed for the top 10 RPNs.

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