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mean time between failures,
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ASSESSING RISK PRIORITY NUMBERS OF FAILURES IN THE SCREW TIGHTENING MACHINE OF A HARD DISK DRIVE PRODUCTION SYSTEM

In a competitive environment, many production industries must reduce costs while maintaining asset value and reliability. In the manufacturing process, the machine is essential because downtime can inhibit and stop production. This study investigated the breakdown trend of a hard disk drive production line in the manufacturing industry to recommend applying Reliability-Centered Maintenance (RCM) for improved productivity, reliability, and availability. This study focused on breakdown analysis, identifying potential failures, and classifying the main components of screw-tightening machines. The RCM method was used based on several tools: failure mode and effects analysis (FMEA), risk priority number (RPN), mean time between failures (MTBF), and mean time to repair (MTTR). The study identified which production line had the lowest availability and productivity due to high downtime and failure rates. In addition, the top-five failures were identified that severely disrupted production These breakdowns were overcome and their occurrence reduced was by calculating and evaluating MTBF and MTTR to help manage failures and indicate the efficiency of corrective action. Thus, this industry and others can achieve better equipment availability and machine reliability using the RCM method.

1. INTRODUCTION

In recent years, industries have been constantly challenged to manage operational excellence and maintenance efficiency while remaining competitive in the global marketplace [1]. Reliability-Centered Maintenance (RCM) is an industrial improvement approach that can most effectively manage the risk of equipment failure [2]. The correct way of using RCM can improve system reliability and availability, decrease the amount of preventive maintenance and unplanned corrective maintenance, and increase safety [3]. RCM combines Preventive Maintenance (PM), Real-Time Monitoring (RTF), Predictive Testing and Inspection (PT&I), Run to Failure (RTF), and Proactive Maintenance to increase

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the likelihood that a machine or component will function as intended over its design life cycle with the least amount of maintenance and downtime while minimizing life-cycle costs [4].

Gusarov demonstrated and focused on improving the reliability of steam engines, improving machine reliability, and reducing maintenance costs as the most critical components in the production of electricity in steam-piston engines and system processes. As a result, reliability could significantly impact every machine and was required to improve operational efficiency [5]. Trukhanov reported calculating the desired reliability of complex systems or machines using failure probability and mean time between failures (MTBF). In this case, the results improved the reliability of complex technical systems, such as mobile facilities [6]. With reference to the Shiraz Refinery in Iran, Ebrahimzadeh et al. discovered that activities with a low risk priority number (RPN) have higher priority than activities with a higher RPN in terms of severity. Furthermore, achieving a high RPN in some activities, such as object handling and transportation, could enable appropriate control measures to be applied to the acceptable risk level, demonstrating the utility and effectiveness of the failure mode and effects analysis (FMEA) method [7]. Wessiani demonstrated that with the results proposed on how to classify based on the FMEA and RPN analysis, and some risk-mitigation measures were suggested that could be implemented when the business process was already running in another study in the poultry production process [8]. Afefy demonstrated the use of RCM in an actual industrial process to reduce total operating costs and breakdown maintenance while increasing system reliability and availability, along with the development of maintenance and downtime metrics [9]. System availability and life cycle cost are some of the key measures to evaluate key performance using the methods of MTBF and mean time to repair (MTTR) [10]. In another study, Ribeiro reported that maintenance management was strategic for production industries. The analysis used MTBF, MTTR, overall equipment effectiveness (OEE), and availability (A) to optimize production equipment performance, reduce costs, reduce lead times, and improve product quality. As a result of such actions, the line became more organized, the MTBF value increased, and the MTTR decreased [11]. Hallquist addressed that failure reporting analysis and corrective action system (FRACAS) provides a structured process for calculating reliability parameters such as MTBF based on real-world system operation data. A failure reporting system's goal is to plan, implement, and track corrective actions in response to the failures under investigation. When used correctly, this system can provide invaluable input to design teams, improve quality, and reduce life cycle costs [12].

In this section, we considered various types of maintenance used in the manufacturing and process industries. Most researchers have concentrated on classic RCM. Some researchers used software, while others did not. Furthermore, an Excel program was used to carry out maintenance programs that reduce maintenance costs while increasing machine availability and the reliability of industrial processes. The primary goal of this paper was to concentrate on the overall approach to working with maintenance in the organization as well as a long-term approach to developing an RCM strategy in manufacturing. This strategy also aimed to improve machine performance, particularly during downtime, and to reduce the likelihood of major component failure. The screw-tightening machine was studied using a FMEA, RPN analysis, and failure metrics (MTBF and MTTR). In addition, breakdown data from the production line was accumulated throughout a one-year period from 2020 June to 2021 July. Finally, the proposed work resulted in guidelines and suggestions for implementing RCM in a screw-tightening machine of a hard disk drive (HDD) manufacturing system.

2. PROBLEM FORMULATION

The following analysis was carried out in a real case study that could be applied in large industries: machine selection and information collection, machine description and functional failures, FMEA, failure metrics (MTBF, MTTR), and downtime analysis. The flow chart of the methodology is shown in Fig. 1.

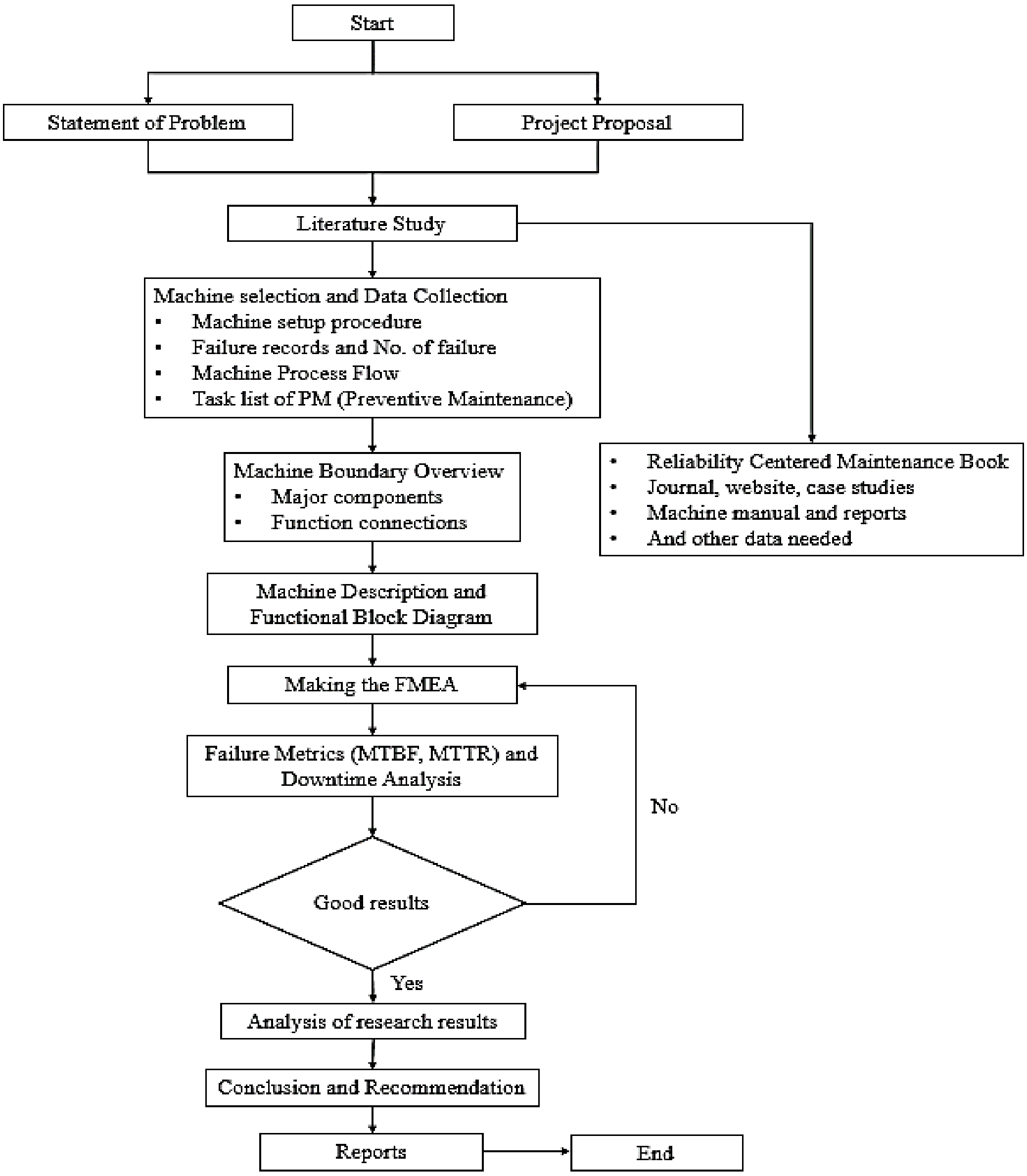


Fig. 1. Methodology Flowchart

2.1. MACHINE DESCRIPTION AND FUNCTIONAL FAILURES

In this part, a machine is defined as a group of components or facilities that support an operational function. The following step collected information about this equipment and determined which functions must be preserved by the machine [13]. Functional failures occur as a result of the definition of machine functions. Typically, each function has two types of failures. A function failure can be a total failure or partial loss of function [14].

2.2. FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

FMEA was performed after identifying potential functional failures. The primary goal of this step is to identify the dominant failure modes, establish the cause and effect relationship between potential equipment failures and functional failures, and evaluate the FMEA worksheet. FMEA must define the component functions, functional failure, failure mode, and failure effects. Each potential failure mode and effect is rated in each of the following three factors. The severity (S) of the potential effect of the failure in terms of harmful effects on operation is rated. This includes the extent of the damage done. Damage can be financial, technological, structural, or work - related or environmental in nature. Occurrence (O), which indicates the likelihood of the failure occurring. The frequency with which a machine fails is related to its reliability. Detection (D), which assesses the likelihood that a problem will be identified before it reaches the end user or customer. This includes the ability to avoid failure (real time monitoring, etc.) The combination of these three factors is known as the RPN and is used to reflect the priority of the failure modes identified. RPN is simply calculated by multiplying three factors after the probability rating has been completed [13].

2.3 MEAN TIME BETWEEN FAILURES (MTBF) AND MEAN TIME TO REPAIR (MTTR)

MTBF is the average time between system breakdowns. MTBF is calculated as the ratio between the total operating time and the total number of failures. The MTBF is expressed mathematically as [15]:

$$\text{MTBF} = \frac{\text{Total operational time}}{\text{Total number of failures}} \tag{1}$$

MTTR refers to the average time required to repair a malfunctioning system and restore it to full functionality. In order to calculate MTTR, sum the time spent on the repairs and divide it by the number of repairs that are performed. MTTR is represented as [15]:

$$\text{MTTR} = \frac{\text{Total maintenance time}}{\text{Total number of repairs}} \tag{2}$$

3. DATA ANALYSIS

The necessary information and documents were gathered from the factory's maintenance team and the process engineering, tooling, and engineering departments between 2020 June and 2021 July. The maintenance worksheet also collected data from the engineering team and the process instruction manual.

3.1. MACHINE DESCRIPTION AND FUNCTIONAL BLOCK DIAGRAM

Figure 2 depicts the functional block diagram of the screw-tightening machine and shows the primary function of the machine from start to finish.

Figure 3 displays the process flow chart of all machine components, their functional relationships, and the in and out interfaces.

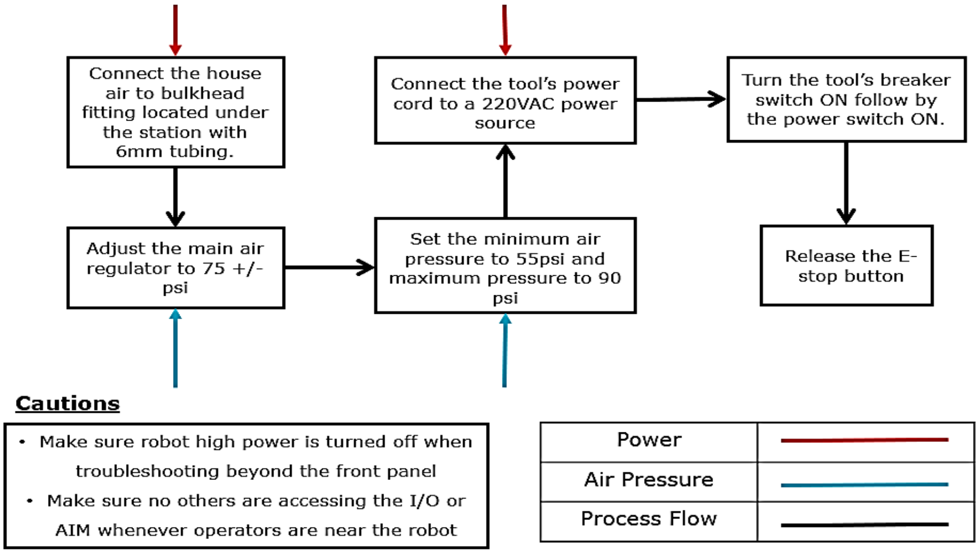


Fig. 2. Screw-tightening machine functional block diagram

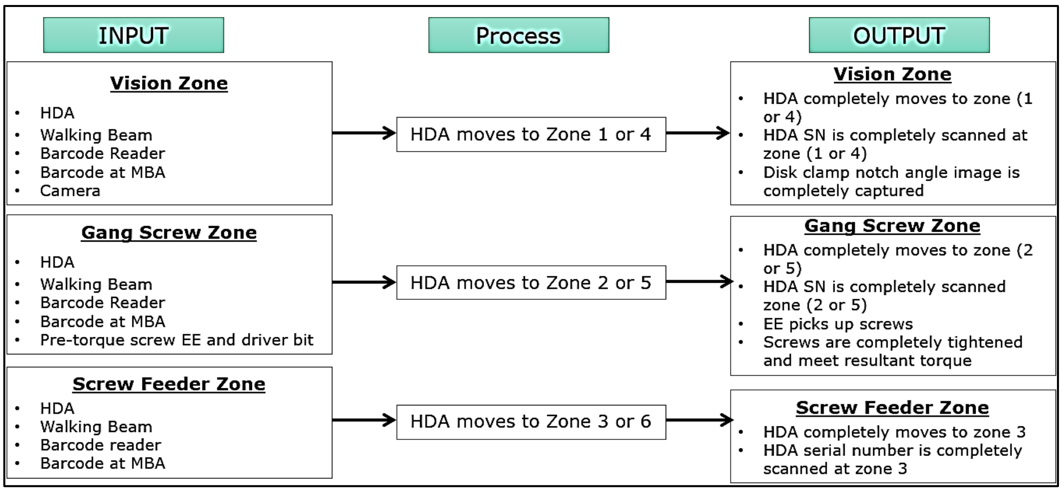


Fig. 3. Screw tightening machine process flow chart

3.2. FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

FMEA is a procedure that combines a failure mode and effect analysis, influenced by severity, occurrence, and detection. The *RPN* was used to prioritize action-taking based on the company parameters ($RPN = S \times O \times D$), where S is the rank of the severity of the failure mode, O is the rank of the occurrence of the failure mode, and D is the rank of the likelihood the failure will be detected (Table 1).

Table 1. Risk Priority Number (*RPN*) calculation and critical indication

Factors for failure mode evaluation						
ID	Components	Failure mode	*S*	*O*	*D*	*RPN*
1.1	Gang driver module	Bit broken	7	3	2	42
1.2		Gang driver alignment out	6	5	2	60
1.3		Gang driver rotation issue	7	4	2	56
1.4		Torque value out control	5	3	3	45
1.5		Torque value out specification	5	3	3	45
2.1	Walking beam	MBA detect sensor issue	4	3	2	24
2.2		Walking beam base biasing-datum not functional	5	4	2	40
2.3		Walking beam crash issue	5	7	3	105
2.4		Walking beam home sensor not on	5	3	4	60
3.1	Vision zone	Cannot scan base	6	3	4	72
3.2		Vision error	6	7	3	126
3.3		Vision job file issue	5	3	4	60
3.4		Vision calibration issue	5	3	4	60
4.1	TECHNART controller torque	TECHNART driver problem	6	4	2	48
4.2		TECHNART controller problem	6	4	3	72
5.1	220VAC power source	Electronic short circuit	7	5	2	70
6.1	Screw pick and place module	Door sensor/Safety alarm	5	4	2	40
6.2		IAI cannot pick up from tray	6	3	2	36
6.3		IAI robot error	6	4	2	48
6.4		Screw pickup issue	6	4	2	48
7.1	Screw presenter	Presenter issue	6	2	3	36
7.2		Rail stuck	8	3	1	24
7.3		Screw feeder problem	8	7	2	112
7.4		Screw high	7	10	2	140
7.5		Screw stuck	7	9	2	126
8.1	Screw pick and place module setting threshold	Pressure dropped	6	3	4	72
9.1	Screw tightening machine	Contamination relate tool	4	9	2	90
9.2		Contamination relate operator	6	7	2	84
9.3		Process verify	8	9	1	90
9.4		Production clear wipe	8	9	1	90
9.5		Sensor malfunction	6	4	2	48
9.6		Software debug	5	3	3	45
9.7		Tool hang	4	7	2	84

3.3. FAILURE METRICS AND DOWNTIME ANALYSIS

Table. 2. Relation between downtimes, number of failures, *MTBF* and *MTTR* of screw-tightening machine on monthly basis

Month	Downtime (hours)	Number of failures	*MTBF* (hours)	*MTTR* (min)
July	64.7	794	45.9	4.9
Aug	57.8	740	49.8	4.7
Sep	54.8	860	54.8	3.8
Oct	52.3	728	51.1	4.3
Nov	65.6	1045	34.8	3.8
Dec	86.3	1212	37.3	4.3
Jan	55.4	806	45.9	4.1
Feb	56.3	865	42.7	3.9
Mar	51.4	898	41.5	3.4
Apr	70.7	1186	35.3	3.6
May	31.9	549	70.0	3.5
June	35.6	848	56.9	2.5

Table 2 depicts the monthly downtimes, failures, *MTBF*, and *MTTR* of a screw-tightening machine in the hard disk drive (HDD) production line from 2020 June to 2021 July. The data show that December and April had the most downtime, with 86.3 and 70.7 hours, respectively. However, the months of May and June had the lowest downtime in the year at around 33 hours. December and April had the most number of failures, with 1212 and 1186, respectively. May had the fewest failures for the year, with 549. After analysing the data, the MTBF for May was noticeably different from the other months and had the highest value of 70 minutes. Overall, there was a slight fluctuation throughout the year. For *MTTR*, the highest repair time of 4.9 minutes was recorded in July, and in the following months this gradually decreased to 2.5 minutes, the lowest repair time of the year.

4. RESULTS AND DISCUSSION

4.1. ANALYSIS OF FMEA RESULTS

Table. 3. Top-5 primary failures of screw-tightening machine

ID	Functional Failure	Failure Mode	Failure Cause	Failure Effect
7.5	Unable to supply screw to gang driver station	Screw stuck	Tool error Alignment failure Flow meter failure Pick and place vacuum failure	Production stops
3.2	Unable to identify, inspect and scan the object to pass through to next station	Vision error	Camera Len loose Alignment error Machine failure Lighting failure	Vision angle collapse and production stops

7.4	Unable to supply screw to gang driver station	Screw high	Overload Insufficient force Alignment error	Production stops
7.3	Screw feeder vibrator does not work properly	Screw feeder problem	Vibrator issue Alignment error Cable broken	Production stops
2.3	Unable to provide the required speed and cannot transfer HDD	Walking beam crash issue	Machine motor failure Machine control failure Software error	Walking beam trips consequently production stops

Table 3 lists the top-5 risk failures by FMEA, ranked by the *RPN*. Based on the company's standard value guideline, we considered high *RPN* risk failures had values greater than 100.

As shown in (Fig. 4), the highest *RPN* of 140 was due to tool error, alignment, flow meter failure, and pick and place vacuum failure with a failure mode of Screw Stuck, resulting in equipment inability to operate and stopped production. The *RPN* for both the Vision Error and Screw High failure modes was 126. Then came issues with screw feeders and walking beams, affecting production directly, with *RPNs* of 112 and 105, respectively.

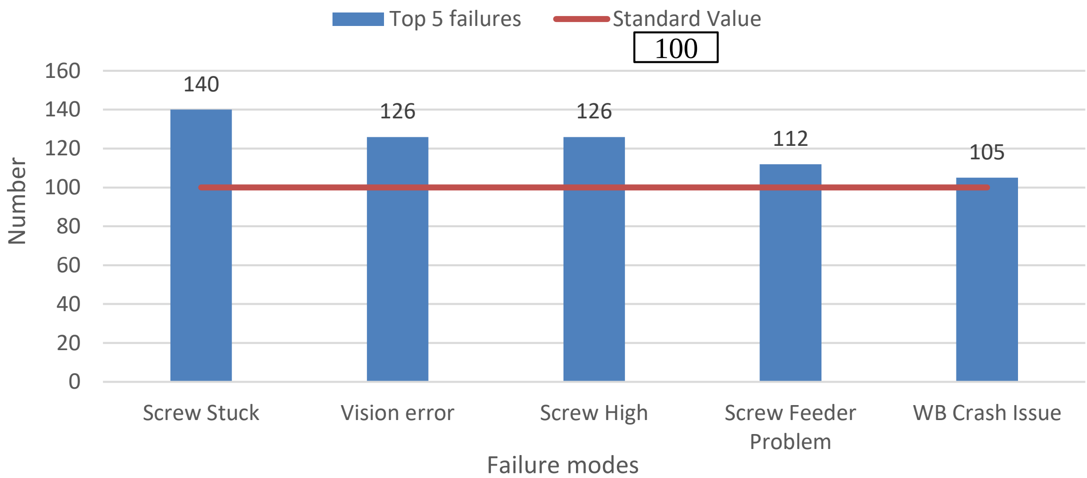
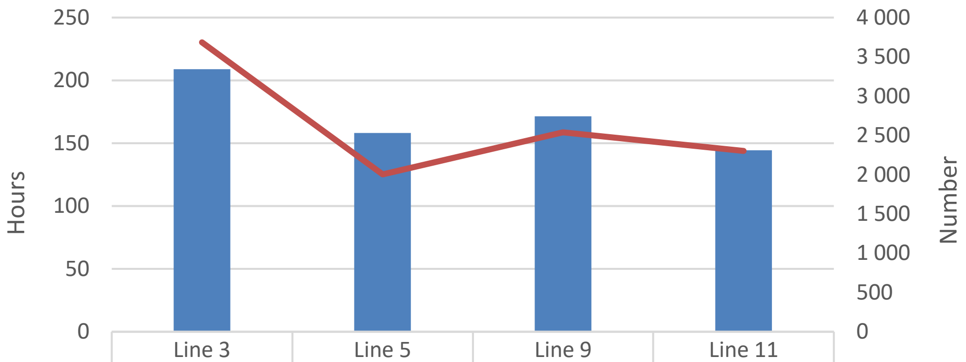


Fig. 4. Distribution of top-5 failure modes of *RPN*

4.2. INDEX RESULTS BY PRODUCTION LINE

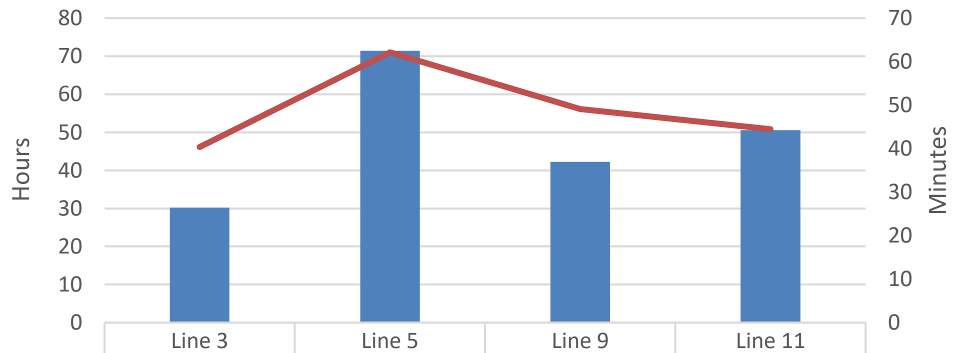
Figure 5 demonstrates the total value of downtime and the number of failures related to the number of lines in a year. Line 3 had the most downtime (208.8 hours) and failures (3,685) and had the worst overall performance throughout the year. Conversely, line 5 had the lowest value of downtime with 158.2 hours and the fewest failures (2,004), indicating the machine was operating effectively and efficiently.

Line 3 had the lowest *MTBF*, which was 30.2 hours, as shown in (Fig. 6), indicating that one piece of equipment on line 3 failed every 30.2 hours. Line 5 had the longest *MTTR* at 62.1 minutes. This index represents the average time it takes to resolve a problem. Thus, line 3 had the poorest overall performance, reliability, and availability of all the production lines. On the other hand, Line 5 had the highest reliability and performance throughout the year.



	Line 3	Line 5	Line 9	Line 11
Downtime	208.8	158.2	171.4	144.5
No. of Failure	3 685	2 004	2 539	2 303

Fig. 5. Distribution of downtime and number of failures by production line



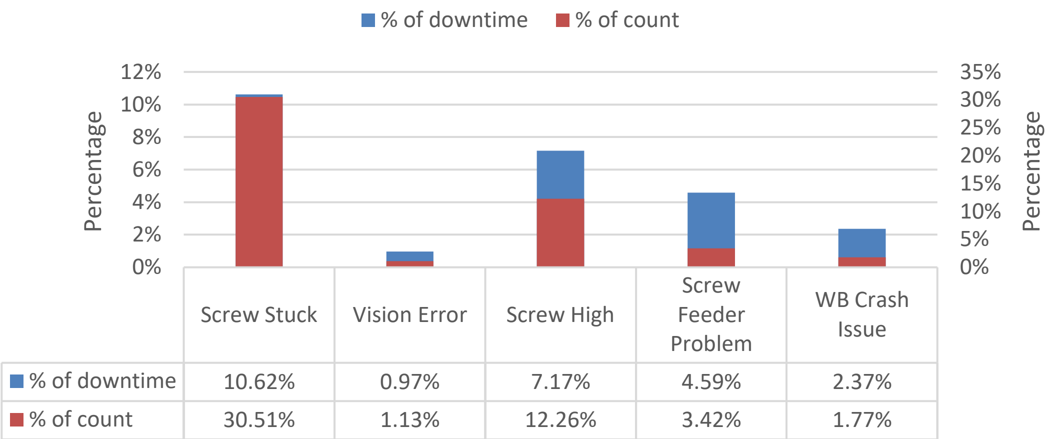
	Line 3	Line 5	Line 9	Line 11
Total (MTBF)	30.2	71.4	42.2	50.6
Total (MTTR)	40.4	62.1	49.1	44.5

Fig. 6. Distribution of *MTBF* and *MTTR* with production lines

4.3. INDEX RESULTS BY FAILURE MODES

According to Fig. 7, the Screw Stuck downtime and occurrence were the highest, with 6,119.8 minutes of downtime and 3,215 failures, respectively. Screw High failure was the second most common, accounting for 3,955.5 minutes of downtime and 1,292 failures. The following failures of screw feeder problem, vision error and WB crash issue had a significantly impact on the machine and production lines as well.

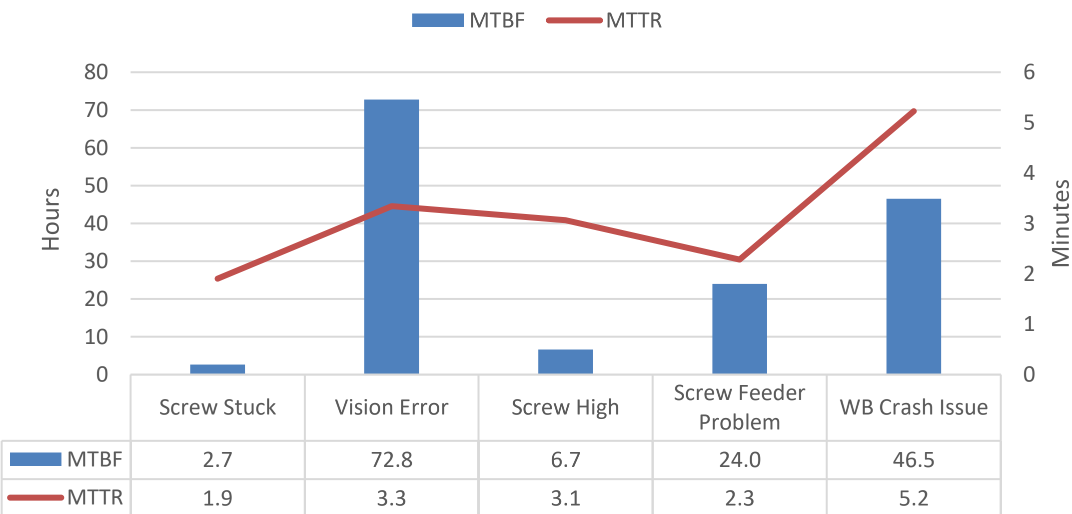
The percentage of failure breakdowns in the screw tightening machine is shown in Fig. 8. Based on the 33 failure modes, Screw Stuck data had the highest percentage. Overall, the top-five failures were the most significant downtime and occurrences, accounting for nearly half of the breakdowns in one year.



	Screw Stuck	Vision Error	Screw High	Screw Feeder Problem	WB Crash Issue
% of downtime	10.62%	0.97%	7.17%	4.59%	2.37%
% of count	30.51%	1.13%	12.26%	3.42%	1.77%

Fig. 8. Relation between % of downtime and % of failure

Figure 9 clearly shows that the *MTBF* value for Screw Stuck was the lowest (2.7 hours) and it was the key failure reducing *MTBF*. This indicated that in this set of machines, a failure occurred every 2.7 hours on average. In terms of *MTTR*, the data showed that the WB Crash Issue required an average of 5.2 minutes to repair when a failure occurred.



	Screw Stuck	Vision Error	Screw High	Screw Feeder Problem	WB Crash Issue
MTBF	2.7	72.8	6.7	24.0	46.5
MTTR	1.9	3.3	3.1	2.3	5.2

Fig. 9. Relation between *MTBF* and *MTTR*

4.4. DISCUSSION

By analysing the hard disk drive production line of the screw-tightening machine, several problems and opportunities for improvement plans could be identified. In order to prevent potential accidents and improve safety in industrial processes, systematic safety management is required. Furthermore, performing preventive maintenance can reduce the likelihood of equipment defects and their consequences. Our findings demonstrated that, when compared to other risk assessment methods, FMEA can allowed the identification of various factors that could create an accident or stop an operating phase and identify more risks. In the current operating context, the following preventive maintenance are assigned for the improvement study of the HDD production system of the screw tightening machine. When there is a need to redesign or modify an item, an effective PM task that will reduce the probability of failure to an acceptable level is required.

Table 4 shows how preventive maintenance was implemented by proceeding through the following stages: monthly calibration, screw feeder and screw pick and place module, screw presenter module, gang screw head module, gang vacuum module, general cleaning, and safety check. These stages ensured that the proposed goals were met and reduced the problems of interference caused by process breakdowns. Table 5 details the corrective and repair actions taken in response to the top-5 primary failures of screw tightening machine as determined by the 5M1E analysis method. Table 6 presents a maintenance plan and the results of a proposed maintenance action in a screw tightening machine. The result shows that the top-5 failures of RPN value were reduced from over 100 to under 100 in screw tightening machine of HDD production.

Table. 4. Preventive maintenance of screw-tightening machine

No.	Description		Condition before			
	Monthly calibration	Pass	Fail	Rect.	Pend.	
1	Inspect switches and LEDs					
2	Robot teach points					
3	Pick position					
4	Placement position					
5	Torque calibration, setup at TECHNART & confirm by MQE resultant torque					
6	Ensure the following are properly connected:	Pass	Fail	Rect.	Pend.	
	1. House vacuum					
	2. Compressed air					
	3. Power supply					
	Screw feeder and screw pick and place module		Condition before			
	Ensure below not worn off or damaged, replace when required.	Pass	Fail	Rect.	Pend.	
1	Screw feeder track					
2	Screw vacuum nozzle					
3	Screw feeder indexing plate					
4	Vacuum filter					
5	Flow sensor					
	Screw presenter module		Condition before			
	Ensure below not worn off or damaged, replace when required.	Pass	Fail	Rect.	Pend.	
1	Presenter nest					
2	Presence sensor					
3	Purge bin collector (remove all screws in it)					
	Gang screw head module		Condition before			
	Ensure below not worn off or damaged, replace when required.	Pass	Fail	Rect.	Pend.	
1	Verify vacuum nozzle are correctly aligned to gage on walking beam.					
2	Vacuum filter					

3	Flow sensor				
4	Guide pins				
5	Loss motion module				
6	Screw finder				
Gang vacuum module			Condition before		
	Ensure below not worn off or damaged, replace when required.	Pass	Fail	Rect.	Pend.
1	Verify vacuum nozzle are correctly aligned to gage on walking beam.				
2	Air cylinder				
3	Vacuum nozzle				
General cleaning		Clean	Particle	Adhesive	Grease
1	Walking beam				
2	screw feeder / indexing plate				
3	screw pick and place nozzle, presenter / gang screw head				
Safety check		Pass	Fail	Rect.	Pend
1	Ensure all guards or cover installed, mountings are secured				
2	Electrical and pneumatic power shall be de-energized (cut-off)	Pass	Fail	Rect.	Pend
	a) Emergency machine off (EMO) is pressed b) Guard doors open				
3	Ensure safety labels are proper, no blur or peeling				

Table. 5. Corrective action of top-5 primary failures of screw-tightening machine

ID	Failure mode	Corrective action	5M1E
7.5	Screw stuck	Clear screw from rail, set alignment rail screw feeder and test pickup screw.	Machine
		Remove screw rotary, set alignment pick and place, pick ID singulator and place presenter.	
		Adjust sensor alignment pick up presenter and adjust control speed screw feeder.	
		Recheck vacuum pick and place, vacuum presenter, reset TSM and recheck main air pressure.	
		Teach point position place screw at lower presenter and rewiring tube screw vacuum upper presenter new.	
		Change part upgrade rail (screw stuck rail often), set alignment screw feeder, set alignment driver, instruct 3 point new.	
3.2	Vision error	Set alignment walking beam zone and confirm vision.	Machine
		Copy file interface vision and remove picture from drive.	
		Reset new load job file vision.	
		After door safety alarm, vision error, action restart 24V direct current and reconnect vision.	
		Camera lens loose and tighten camera lens.	
		Adjust light source, calibrate vision, confirm EEF NC.	
		Turn on breaker I/O, Reset RT, set alignment screw driver and run again.	
7.4	Screw high	Confirm walking beam, set alignment position torque screw from gage, set alignment TECHNART driver and adjust encoder.	Man
		Set alignment part screw for driver, set alignment screw feeder, and set alignment bias.	

		Set alignment gang driver and change collar walking beam datum X, Y and confirm gage NC.	
7.3	Screw feeder problem	Check screw feeder, check vibrator amp, check wiring, check small connect vibrator to screw feeder, and check big connect lifter screw feeder. (Cause: wiring big connect for lifter loose, rewiring)	Machine
		Change screw feeder, set alignment singulator and control speed screw feeder alignment pick up screw.	
		Clear screw at screw feeder and check screw feeder cable connector.	
2.3	Walking beam crash issue	Set alignment walking beam lifter and confirm walking beam bias.	Machine
		Software debug. (reboot monitor and reset)	
		Change screw lock lifter and confirm pick position.	
		Instruct pick and place transfer, reset walking beam, restart and run.	
		Repair lift to teach pick - place position.	

Table. 6. Maintenance plan and action result of top-5 primary failures of screw-tightening machine

ID	Failure modes	Seve-rity	Occur-rence	Detec-tion	*RPN* score	Maintenance plan
7.5	Screw stuck	5	8	2	80	Define preventive maintenance period and cleaning frequently. Implement obstruction detection failure. Add screw obstruction feature.
3.2	Vision error	6	5	2	60	Need to develop vision capability to detect correct notch for disk clamp supplier. Material: review critical dimensions, related to vision capability, between disk clamp suppliers and request for improvement. (e.g. make surface finishing)
7.4	Screw high	6	6	2	72	Define high obstruction by using check sheet and gauge setup. Need to define preventive maintenance action and period. Implement obstruction detection failure.
7.3	Screw feeder problem	5	6	2	60	Add item in check sheet and screw obstruction feature. Resolve incomplete information sent to manufacturing control. Remove screw feeder, clear screw under screw feeder and realign screw feeder.
2.3	Walking beam crash issue	5	4	3	60	Generate procedure to setup walking beam. Upgrade walking beam mechanism to rev.04 for all production line. Walking beam damage check sheet and gauge setup.

5. CONCLUSION

In this paper, an overall analysis was made of the initial condition of the production line, where the main problems and failures were identified by applying several tools such as the FMEA, *RPN*, *MTBF*, and *MTTR*. The FMEA was used to identify the main components, classify failures, and assess risk in the hard disk drive production line. Then, the *RPN* was calculated based on the risk impact, likelihood, and detection. The screw-tightening machine identified 33 failures, five of which were major. The top-5 failures were chosen based on the *RPN*, being greater than 100. The screw-tightening machines on the four production lines had approximately 683 hours of downtime in one year. Screw Stuck failure had the most severe effect on breakdown and was the most serious issue for the screw-tightening machines in the production lines. Following that, the preventive maintenance and corrective actions were performed on top-5 failures of screw tightening machine. The new finding of this work shows that corrective maintenance reduces the risk priority number (*RPN*) values from over 100 to less than 100 after implementing a proposed maintenance plan. The objectives were to find the most cost-effective and applicable maintenance technique for reducing the risk and impact of failure on individual components of failure modes and their causes and effects. Identifying these would help both operators and maintenance technicians to quickly identify and fix machine issues. The identified problems were discussed and solutions provided, allowing the company to expand this improvement technique to other machines.

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