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Total Productive Maintenance Analysis on Printing Machine (A Case Study in an Indonesian Flexible Packaging Manufacturer)

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ABSTRACT: PT XYZ is one of Indonesia's major flexible packaging manufacturer companies. The company suffers losses from the increase in printing machine breakdown from 1.65% in 2019 to 2.52% in 2021. This paper aims to reduce the breakdown duration in 2022 by identifying and solving the root cause by implementing one of the alternative solutions. The primary data are collected via a series of interviews and from the company's manufacturing reports. Using Current Reality Tree (CRT) the root cause was identified as a lack of regular maintenance evaluation and improvement. The study proposes three alternative solutions: Planned Maintenance (PM), Autonomous Maintenance (AM), and condition-based maintenance using IoT sensors. In determining the preferred alternative, the study uses Analytic Hierarchy Process (AHP) with five criteria: OEE improvement, human capital improvement, Capex required, Opex required, and ease of implementation. Align with the AHP result, the company agreed to implement Planned Maintenance (PM). After the first two months of implementation, the average year-to-date breakdown in 2022 was reduced to 2.29%.

KEYWORDS: Flexible packaging, OEE, Planned maintenance, Printing machine, Total Productive Maintenance

1. INTRODUCTION

As the world's fourth most populous nation, Indonesia has a large market for flexible packaging. The flexible packaging is primarily used for fast-moving consumer goods such as foods, beverages, personal care, and home care. In terms of manufacturing cost, logistic cost, and carbon footprint, flexible packaging is intrinsically favored when compared to other packaging formats. For example, transporting 200 ml beverage glass bottles in crates equals carrying only 48% of the beverage by weight and the other 52% for the glass packaging. In contrast, by using flexible packaging, 94% of the weight carried can be occupied with the beverage while only 6% of the total weight is used for the packaging [1].

The flexible packaging manufacturing process in PT XYZ consists of three sequential processes: printing, laminating, and finishing. The printing process has the lowest production capacity and it becomes the bottleneck of the whole production process. The overall throughput of a production system is limited by the processing capacity of the bottleneck process [2]. As a bottleneck, any unplanned downtime in the printing machine will cause a reduction in the company's overall yield.

Figure 1. Printing Machine (source: www.wh.group)

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Compared to the available time, the breakdown duration in the printing section in 2021 is 2.52%. Assuming that the breakdown in 2021 did not happen, the company would have been able to produce an additional 12 million running meters of finished goods throughout the year. The management of the company begins to raise their concern after the fact that the machine breakdown percentage in 2021 has increased to more than 150% when compared to the number in 2019. The increase of breakdown frequency or the deterioration of Mean Time Between Failures (MTBF) can be an indicator to investigate the physical degradation mechanisms in action [3]. The company has implemented some measures of preventive maintenance; however, the increase in breakdown percentage in the printing section shows that the current strategy is ineffective. Therefore, the research is needed to find the root cause of the problem, propose an alternative solution, and evaluate the result of the implementation.

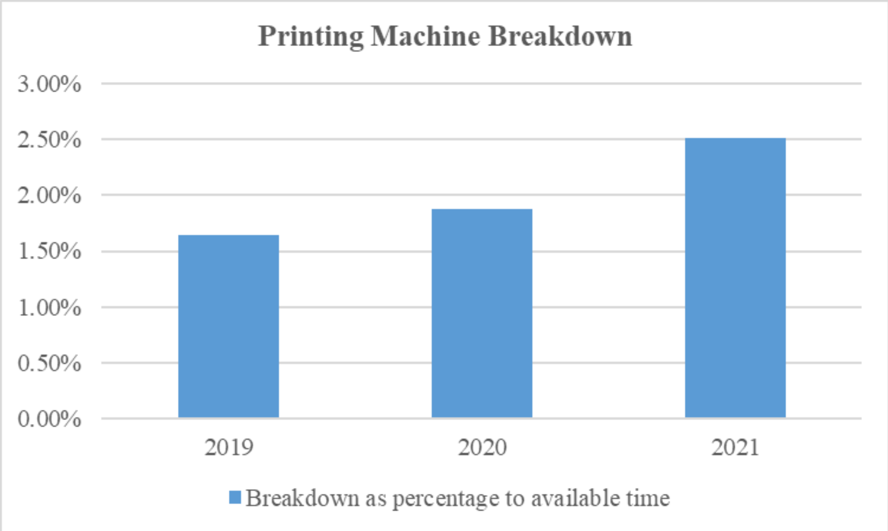

Figure 2. Printing machine breakdown in 2019, 2020, and 2021 (source: PT XYZ)

The research is aimed to reduce the total breakdown of the two printing machines in the West Java Plant. The actions will emphasize the Engineering Department’s standpoint.

2. METHODOLOGY

The action research methodology is used to get a higher level of practical relevance of the research and to gain better understanding about the actual problem in the field. Action research uses a cyclic or spiral process which alternating between the diagnosing, action planning, action taking, evaluating, and specifying learning.

The diagnosing step begins with stating the business issue of the increasing machine breakdown between 2019 and 2021. In evaluating the current condition of the company, the author uses a mixed-method between quantitative and qualitative analysis using OEE data and series of interviews with the stakeholders. After the interview, undesirable effects (UDEs) are identified. The UDEs are then arranged into the Current Reality Tree (CRT) to identify the root cause of the business issue.

Once the root cause of the problem has been identified, the research continues with the action-planning step. Three alternative solutions are prepared and among the three, the best alternative is proposed to the management of the company. To determine which solution is the most suitable to be implemented, the researcher compares the three alternatives in regards to OEE prediction, strengths and weaknesses comparison, and Analytic Hierarchy Process (AHP). The Engineering Manager, Production Manager, and Human Resource Manager of the company are chosen as respondents for AHP.

The action-taking step consists of two major activities, namely office task and field task. The office task includes the preparation of maintenance task list, inspection checklist, breakdown analysis, and troubleshooting handbook. Whereas the field task covers the actual maintenance activities on the shop floor. Before the regular time-based maintenance, a restore basic condition is performed for each printing machine.

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In the next step, the effectiveness of the implementation is evaluated. The two quantitative parameters used for the evaluation are breakdown rate and the OEE of the printing machines. Lastly, the learning outcome of the study is specified. The conclusion answers the research questions of the root cause, the selected solution, and the implementation result.

3. RESULT

OEE or Overall Equipment Effectiveness is an effective tool to measure and analyze the efficiency of a single machine [4]. By analyzing the OEE, the information on the sources of lost production and lost time can be measured [5]. OEE is needed because a traditional productivity matrix (i.e. throughput and utilization rate) is not very helpful for identifying the fundamental problems and opportunities for productivity improvement in an organization [6]. OEE is calculated as the product of three contributing factors, availability, performance, and quality [4].

$$\text{OEE} = \text{availability x performance x quality}$$

Analysing the 2021 manufacturing report provided by the company, the OEE of the printing section is calculated in Table 1. The OEE of 69.82% is fairly typical for manufacturers. However, the ideal OEE for a world-class manufacturer according to Nakajima is above 85% with availability, performance, and quality above 90%, 95%, and 99% respectively [4]. Among the three variables, the company needs to prioritize improving the existing 74.45% availability, which is far lower compared to performance and quality.

Table 1. OEE of the printing section in 2021 (source: PT XYZ)

Month	Availability	Performance	Quality	OEE
Jan-21	80.43%	97.95%	97.21%	76.58%
Feb-21	75.96%	97.29%	96.45%	71.27%
Mar-21	80.58%	98.78%	97.03%	77.23%
Apr-21	77.59%	99.66%	96.68%	74.75%
May-21	70.99%	84.98%	97.03%	58.54%
Jun-21	66.32%	94.18%	96.30%	60.16%
Jul-21	73.44%	94.56%	96.34%	66.90%
Aug-21	71.90%	93.41%	96.87%	65.05%
Sep-21	73.73%	95.12%	96.85%	67.92%
Oct-21	71.67%	95.93%	96.68%	66.48%
Nov-21	75.50%	96.54%	96.46%	70.31%
Dec-21	74.95%	96.98%	96.48%	70.13%
Avg-21	**74.45%**	**95.59%**	**96.70%**	**68.82%**

Machine breakdown is among the unplanned downtime that causes the reduction in machine availability or time efficiency. To identify the undesirable effects (UDEs) related to the increase of machine breakdown in the printing section, the authors conduct a series of interviews with the Engineering Manager, the Preventive Maintenance Planner, the Maintenance Technician, the Production Manager, the Printing Machine Operator, and the Human Resource Manager. By arranging the UDEs into the Current Reality Tree (CRT), the root cause of the problem is identified as a lack of regular maintenance evaluation and improvement.

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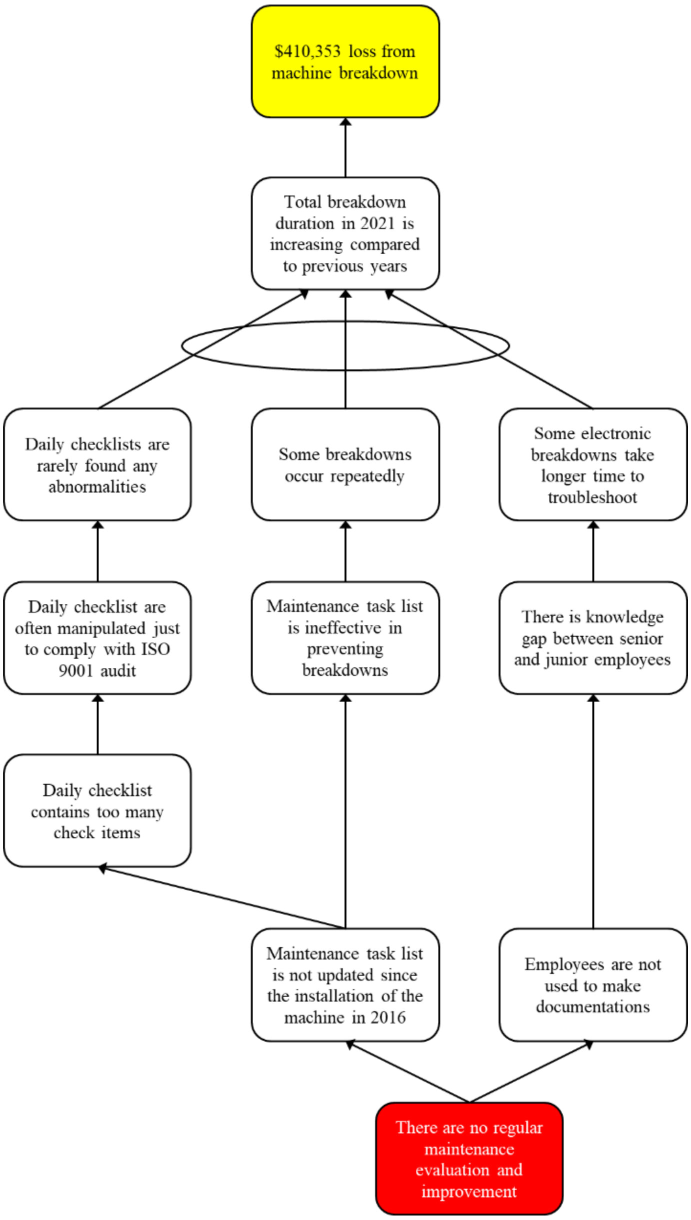

Figure 3. Current Reality Tree (CRT)

After the root cause was identified, the authors come up with three alternative solutions. The first alternative, Planned Maintenance (PM), is one of the eight pillars of Nakajima's TPM. PM pillar is a strategy to achieve the goal of zero breakdowns in TPM [7]. The pillar aims to reduce machine breakdown by fixing the equipment before its failure. The scheduling of the maintenance activities is based on the historical data of the machines, such as failure rates and breakdowns. The implementation is started by restoring the equipment to the basic condition to reinstate the machine back to its prime condition in terms of production speed and quality. The next step is to create a time-based maintenance task list as exemplified in Table 2. The task list is created based on the machine manual book, the historical breakdown data, and the Quality Plan of the printing process. The maintenance task list has to be updated regularly based on the breakdown occurrences. Maintenance intervals can also be adjusted to find the balance between machine reliability and maintenance cost. The planning of maintenance and top management commitment in conforming that maintenance is a core competence is necessary to sustain the competitive advantage of a company [8].

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Table 2. Example of PM task list

Machine	Unit	Sub-unit	Part	Activity	Interval
PR01	Unwinder	Axis	Chuck	Repair	6 months
PR01	Unwinder	Axis	Bearing	Replace	9 months
PR01	Unwinder	Axis	AC motor	Clean	4 months
PR01	Unwinder	Axis	Timing belt	Replace	24 months
PR01	Infeed	Dancer roll	Bearing	Replace	9 months
PR01	Infeed	Nip roll	Rubber roll	Grinding	12 months
PR01	Infeed	Nip roll	Load cell	Calibrate	3 months

The second alternative, Autonomous Maintenance (AM), is also taken from one of the TPM pillars. The pillar emphasizes machine operators' involvement in performing minor maintenance tasks on their machines. The implementation is started with the initial cleaning of the equipment by the operators and technicians. Fuguai or the machine abnormalities found during the initial cleaning are recorded to be repaired by the technicians [9]. A red tag will be placed on the equipment to indicate the abnormality location and a work request to the Engineering Department will be made. After the initial cleaning, minor maintenance tasks such as cleaning, inspection, lubrication, and tightening are performed regularly by the machine operators. By autonomously carrying out regular maintenance, the operators will develop the responsibility to ensure the equipment were able to achieve high productivity and quality [10]. Another advantage of transferring inspection activity from technicians to operators is that the operators are present and working with the machines every day, which makes the operators more aware of the subtle changes in their machines. By being able to detect abnormalities earlier, the technicians could have more time to fix the abnormalities before the equipment failure or machine breakdown happens.

Figure 4. Example of red tag in AM implementation

The third alternative is condition-based maintenance using IoT sensors. This alternative focuses on utilizing sensors to collect real-time data on equipment conditions. In the era of Industry 4.0, the Internet of Things (IoT) has become widely adopted in production machines. Multiple wireless sensors are now available in the market at more affordable prices. IoT technologies make it possible for machine-to-machine communication to acquire the machine condition data (e.g. vibration and temperature) in real-time. Accurate prediction of such failures using sensor data can prevent or reduce the breakdown of valuable assets [11]. The sensors can be installed on the equipment to send the real-time measurement to the company's server to be analyzed. The collected data can be transformed into information for condition-based maintenance to inform the technicians when the equipment needs further maintenance activity.

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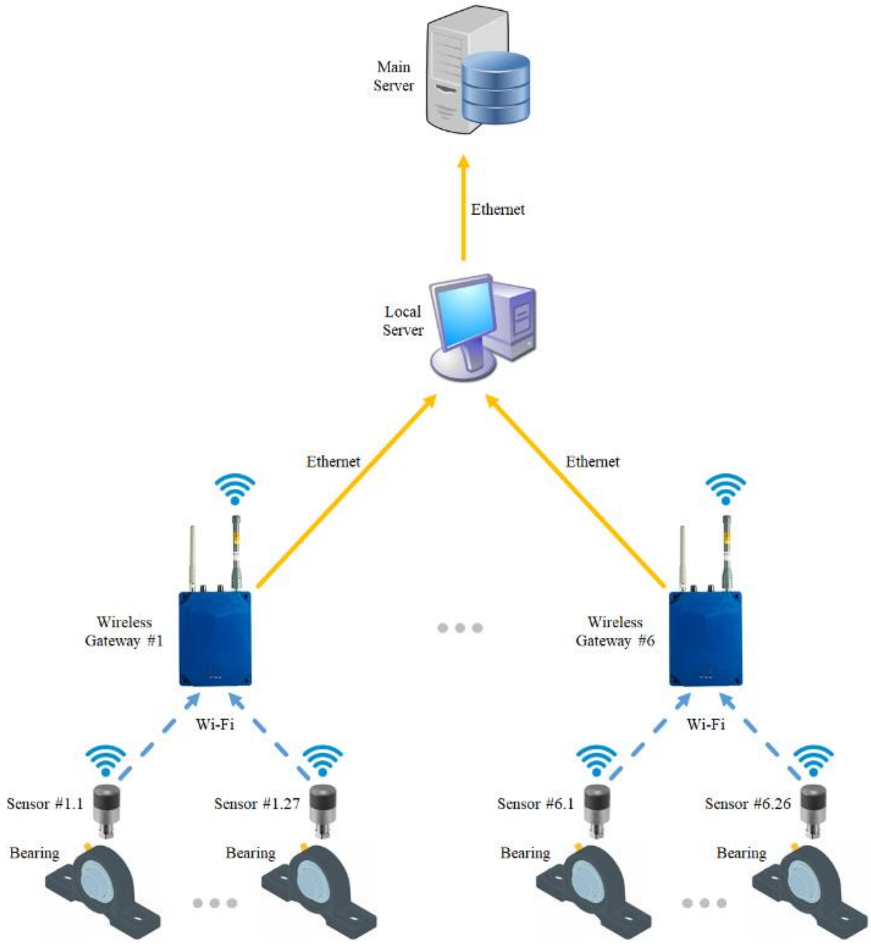

Figure 5. Sensors installation and network topology

When the alternatives are compared, planned Maintenance offers the most benefit in reducing machine breakdown with its comprehensive task list. It also allows the company to constantly evaluate and improve its maintenance strategy. Even though the alternative possesses promising benefits, the Planned Maintenance is high on operating expenses for maintenance costs. Time-based replacement means that the equipment will be replaced or maintained regardless of the condition. The maintenance activity is also labor-intensive and requires machine downtime every three months.

Some Autonomous Maintenance (AM) activities are similar to Planned Maintenance. However, the activities are mostly performed by the printing machine operators instead of technicians. Transferring the activities to the operators will increase the participation of the operators in a collaborative effort in maintaining the equipment. Because the AM is performed every week, the machines are cleaner and abnormalities can be detected sooner compared with PM activities which are performed every three months. The most significant drawback of Autonomous Maintenance is that the activities occupy a significant portion of operators' time and potentially disrupt operators' focus on product quality. Some operators might resist the change because they believe that performing machine maintenance is the job of the Engineering Department and not theirs. Intensive training, coaching, and supervision will be needed to grasp the effectiveness of Autonomous Maintenance.

The last alternative solution, condition-based maintenance using IoT sensors, is excellent in eliminating the subjective judgment on inspecting the machine's condition. The machine condition is quantitatively measured by the vibration and temperature sensors. The operating cost is also the least compared with the previous two alternatives because of the condition-based approach. The technicians will only replace the part when the condition is abnormal. The solution, nonetheless, is only able to cover a lesser

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portion of the breakdown categories. Furthermore, the installation of sensors will require high Capex in the beginning. Because of the limited scope of the IoT sensors, the solution can only provide limited room for continuous improvement and evaluation.

Table 3. Strengths and weaknesses comparison

Alternative solutions	Strengths	Weaknesses
Planned Maintenance (PM)	• Less machine breakdown and the most effective alternative in increasing the OEE • Allows more thorough evaluation and improvement • Increases technicians' skill	• Higher in maintenance cost because of time-based focus • More labor-intensive • Require planned maintenance downtime every three months
Autonomous Maintenance (AM)	• Increases operators' participation and sense of belonging to the machines • Increases operators' skill • Faster in detecting abnormalities	• Occupies more of operators' time, potentially less focus on product quality • Does not cover higher-difficulty maintenance • Most difficult to implement and require intensive operator training and coaching
Condition-based maintenance using IoT sensors	• Eliminates subjective judgment on inspection of machine condition • Lower maintenance cost because of condition-based focus • Least labor-intensive	• Only covers a small portion of breakdown categories and is least effective in increasing the OEE • High in Capex • Limited room for evaluation and improvement

To determine which alternative to be proposed to the company, the authors use Analytic Hierarchy Process (AHP) with the Engineering Manager, the Production Manager, and the Human Resource Manager as the respondents. Each alternative is evaluated using a pair-wise comparison from the five criteria: OEE improvement, human capital improvement, Capex (capital expenditure) requirement, Opex (operating expenses) requirement, and ease of implementation. At the end of the analysis shown in Table 4, Planned Maintenance (PM) is determined as the most preferable alternative by the stakeholders with a 0.46 score. Autonomous Maintenance (AM) comes second, while Condition-based maintenance using IoT sensors is deemed as the least preferable alternative.

Table 4. AHP result

Criteria	Weight
OEE improvement	0.46
Human capital improvement	0.27
Capex (capital expenditure) requirement	0.10
Opex (operating expenses) requirement	0.07
Ease of implementation	0.10
Alternatives	**Score**
Planned Maintenance (PM)	0.46
Autonomous Maintenance (AM)	0.35
Condition-based maintenance using IoT sensors	0.19

After a discussion with the stakeholders, the company agreed to implement Planned Maintenance (PM) in the printing section as a pilot project. The implementation was started with restore the basic condition of the two printing machines. The Fuguai or

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abnormalities detected during the restore basic condition were recorded in the Abnormality List to be repaired by the maintenance technician.

Figure 6. Before and after restore basic condition (source: PT XYZ)

The second step of the installation is to create a maintenance task list bases on the machine failure rate. From the three sources (i.e. manual book, historical breakdown data, and Quality Plan), the team collected 469 maintenance activities with intervals varying from every two months until every two years.

After the first two months of implementation, the breakdown in the printing section had been reduced from 2.52% to 2.29%. As shown in Table 5, the improvement of printing machine breakdown was not followed by the improvement of OEE. Although both availability and performance are improved, the quality is worsened, resulting in -0.04% changes in OEE. The deterioration in quality, however, was identified as an isolated case and does not have any connections with the PM implementation.

Table 5. Breakdown and OEE after PM implementation (source: PT XYZ)

Category	Before	After	Changes
Breakdown	**2.52%**	**2.29%**	**-0.23%**
OEE	**68.82%**	**68.78%**	**-0.04%**
Availability	74.45%	74.80%	+0.35%
Performance	95.59%	95.76%	+0.17%
Quality	96.70%	96.02%	-0.68%

4. DISCUSSION

The reduction in average machine breakdown in 2022 indicates that there is an improvement after the implementation of Planned Maintenance. In his book, Nakajima explained that one of the PM pillar goals is to achieve zero breakdowns. He also emphasized that such a goal cannot be achieved overnight [4]. The data after the implementation is in line with the statement of Nakajima. Although as of March 2022 the company has not been able to achieve zero breakdowns, positive progress can already be observed. Even so, the result of the study is generalized due to the limitation of the observation duration which is only three months. Longer observation is needed to get a better picture of the implementation result.

The result also confirms the statement from the previous research in another Indonesian flexible packaging manufacturer [12]. In the research, the authors conclude that the inconsistency in preventive maintenance implementation and lack of autonomous maintenance will lead to machine deterioration. The authors also highlighted that the improper machine condition will lead to not only machine breakdown but also a high rejection rate that causes a further decrease in OEE.

In another study from one of the flexible packaging manufacturers in Pakistan, Shehzad et al. concluded that successful implementation of 5S and TPM will result in a significant reduction in mechanical downtime. The study reported that the OEE has improved from 50% to 53%, indicating an improvement in productivity and improvement in the quality of the product [13].

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The study provides insight between Planned Maintenance implementation and the reduction of machine breakdown. The pilot project in the printing section can be rolled out to the blowing, laminating, and finishing section in the company. After the implementation of Planned Maintenance, other pillars of TPM such as Autonomous Maintenance (AM) and Quality Maintenance (QM) may follow.

5. CONCLUSION

This research found that to reduce the machine breakdown, firstly, the root cause has to be identified. By using CRT, a lack of maintenance evaluation and improvement is identified as the root cause. The maintenance task list that had not been updated since the first installation of the machine caused the breakdown to increase as the machine ages.

Secondly, the root cause has to be answered by one of the alternative solutions. The study proposed three alternative solutions to be compared Planned Maintenance (PM), Autonomous Maintenance (AM), and condition-based maintenance using IoT sensors. AHP is used to determine which solution to be proposed to the company and the AHP result shows that Planned Maintenance (PM) is the best alternative. Align with the AHP result, the company decided to implement PM for both printing machines.

Lastly, after the PM implementation, an improvement in breakdown duration in the printing section was observed. The 2.52% breakdown was successfully reduced to 2.29% after the two months of PM implementation.

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