Optimization of Printing Equipments Through Overall Equipment Effectiveness (OEE) Measures

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Abstract

This research investigates the implementation of Overall Equipment Effectiveness (OEE) as a key performance metric to optimize productivity in a packaging industry using offset printing technology. The problem identified was high production waste and machine downtime, particularly in the OP-18 printing unit. The study applied a structured methodology involving Time and Motion Study (TMS), Single Minute Exchange of Dies (SMED), Planned Maintenance (PM), and Group Dependent Scheduling (GDS) to enhance equipment performance. OEE was calculated based on three core components: Availability, Performance, and Quality. Initial observations revealed an average OEE of 28%, primarily due to mechanical failures, prolonged setup times, and inconsistent machine speed. After systematic implementation of the proposed strategies, the OEE improved to 56%, with Availability increasing from 60% to 90% and Performance from 54% to 66%, while maintaining Quality at 95%. The results demonstrate that targeted lean manufacturing tools can significantly enhance equipment efficiency in industrial settings. This model provides a framework for replication across similar processes. Future work includes exploring the impact of input materials on quality and testing the scalability of this model in other industrial sectors.

Keywords—Overall Equipment Effectiveness (OEE); Single Minute exchange of Die (SMED); Planned Maintenance (PM), Delay in setup time; Printing Machine

1 Introduction

PERFORMANCE is the degree to which a company's or its processes' current state satisfies its goals. Process performance measurement provides insight into the current state of the processes and facilitates decision-making on configuration changes or other activities aimed at improvement [21]. In settings involving large manufacturing, overall equipment effectiveness is a crucial performance metric. Nakajima [2] introduced OEE, which is focused on machinery and equipment, in the framework of Total Productivity Maintenance (TPM). Since OEE is an easy-to-understand aggregate metric, managers value it over numerous more specific metrics [3]. Due to severe capacity constraints on facility investment, Gupta and Garg [4] report that the notion of OEE is gaining traction and is frequently utilized as a quantitative instrument crucial for measuring productivity in semiconductor manufacturing operations. They claim that throughput and utilization—two common metrics used to measure productivity—are insufficient to pinpoint the issues and fundamental adjustments required to boost output. Since OEE is an easy-to-understand aggregate metric, managers value it over numerous more specific metrics. According to Iannone and Nenni [5], a severe capacity constraint on facility investment has led to a widespread adoption of the idea of OEE as a quantitative tool crucial for mea-

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suring productivity in semiconductor manufacturing processes. It is argued that the traditional metrics, like throughput and utilization, are inadequate for identifying issues and solutions needed to improve output. They claim that the throughput and utilization metrics—traditional measures of productivity—are inadequate for pinpointing issues and underlying fixes that are required to boost output. They claim that the throughput and utilization metrics—traditional measures of productivity—are inadequate for pinpointing issues and underlying fixes that are required to boost output [6].

The research is based on practical implications. The overall exposure is equipped with real-time practices. While this study is limited to the offset printing process, the OEE optimization approach using SMED, Planned Maintenance, and Group Dependent Scheduling has broader applicability. The core methodology—identifying key loss areas, implementing focused improvement tools, and monitoring through time-motion studies—is industry-agnostic and can be adapted to various discrete manufacturing sectors such as automotive, textiles, and food processing firms. The aim of this research is to assist in developing an understanding of the industrial practices in the packaging industry and to contemplate the hurdles that create barriers in meeting the everyday challenges and bring improvement in daily executions.

2 Literature Review

2.1 Finding Sustainability Performance

Overall equipment effectiveness (OEE) is a hierarchy of metrics developed by Seiichi Nakajima in the 1960s to evaluate how effectively a manufacturing operation is utilized [7-9].

OEE (Overall Equipment Effectiveness) is the gold standard for measuring manufacturing productivity. OEE measurement helps in identifying the underlying losses and improving the productivity of equipment. The OEE calculation incorporates the three important factors as per Maideen, et al. [10], that are as follows:

- Availability: While considering scheduled and unscheduled Stops. An available score of 100% means the process is on the move during scheduled production Time. $Availability = Runtime/availabletime$
- Performance: While considering small stops and low-speed operations. An available score of 100% means the process is at its peak speed. $Performance Realproduction/IdealProduction$
- Quality: While considering defects (including reworking and complete parts). An available score of 100% means zero defects (only zero-defect parts are being produced).

$$Quality = GoodParts/Realproduction \tag{1}$$

The formula to calculate OEE is:

$$OEE = Availability \times Performance \times Quality \tag{2}$$

2.2 Single Minute Exchange of Dies (SMED)

SMED was formulated by Shigeo Shingo [11, 12], who helped industries significantly reduce changeover time. He did groundbreaking and leading efforts to reduce changeover time by 94% (e.g., from 90 minutes to less than 5 minutes). SMED helps significantly to reduce changeover time [13]. The objective of using SMED is to reduce the changeover time to a single digit. An effective SMED leads to the following positive outcomes:

- Reduction in manufacturing costs (less changeover time means less time for less downtime). Small batch/lot size means fast changeover, which enables quicker production change.
- Better response to customer demand (compact batch/lot size enables more flexible and easier scheduling.
- Small inventory (company / small batch/lot size leads to reduced inventory level)
- More seamless start-ups (standardized changeover processes improve consistency and quality)
- In SMED, changeovers are made up of steps that are termed “elements” [14]. There are two types of elements:
- Internal Elements (elements that must be completed while the equipment is stopped)
- External Elements (elements that can be completed while the equipment is running)

The SMED approach focuses on making as many elements as possible external, and simplifying and streamlining all elements [15].

2.3 Planned Maintenance

Planned maintenance refers to maintenance activities that are documented and scheduled to take place before any breakdown occurs, unlike unplanned maintenance which happens after a failure. By organizing maintenance tasks in advance, the process becomes more efficient and minimizes disruptions to the facility’s operations. In planned or scheduled maintenance, both the tasks and their timing are predetermined.

The triggers for such maintenance include those typically used in scheduled maintenance [16], such as event-based, usage-based, time-based, and condition-based triggers.

Since everything is arranged beforehand, resource requirements are already known and can be prepared in advance. Similarly, the exact timing for maintenance is also predetermined. When resource planning is combined with scheduling, all necessary materials and personnel are ready to begin as soon as the job starts, making the process smoother and more efficient.

Planned maintenance can be arranged with either short or long lead times. Some activities are scheduled years ahead—like replacing air-conditioner filters every year before summer—while others follow shorter schedules based on equipment usage [17].

For maintenance technicians, planned maintenance is far more efficient than unplanned work, as the nature of the task is already known. This allows for the necessary parts and supplies to be ready in advance, and any surrounding equipment that might pose safety risks can be shut down beforehand. As a result, planned maintenance jobs are completed faster, and equipment can return to operation sooner [18].

2.4 Group Dependent Scheduling

Group-dependent scheduling works under the same principle as that of Group Technology (GT) and defines GT as the unification of parts and pieces within groups [19]. When a job shop schedule is being elaborated, it is necessary to be guided by some criteria, either customer service criteria or production effectiveness criteria[20]. This experiment focuses on the production effective criteria, as this criterion would help in reducing the setup time, and the machine would perform effectively under the same working parameters for each group of products [21].

3 Materials and Methods

The methods and materials have been categorized into three phases. The plan below (see figure 1) illustrates the transformation from AS-IS into TO-BE. The action plan has been written below for every phase.

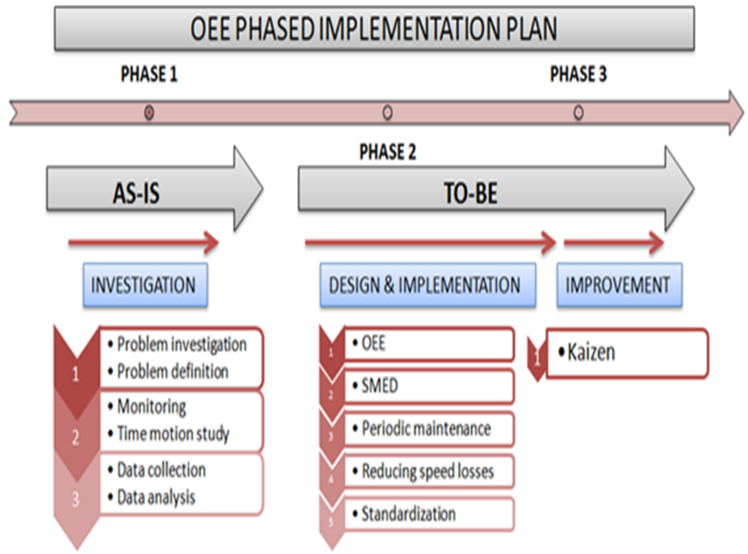


Fig. 1: OEE Implementation Plan

3.1 Phase I

3.1.1 *Investigation*

The chosen industry offers Offset and Gravure printing technologies, out of which Offset was examined. Below is the process flow of Offset printing (as shown in Fig. 2):

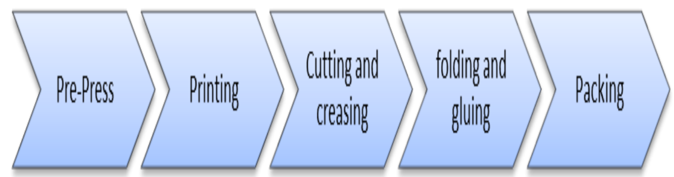


Fig. 2: Stage-wise process flow of offset printing

The printing press was chosen for this study as 80% of the product cost is incurred at the printing stage, and the printing press itself is a vast setup to attain good learning prospects. A Printing Press is a prime operational resource of any printing and packaging firm. Therefore, timely investments and improvements in the process will produce a product of good quality with maximum output at the initial stage and thus will reduce the chances of failure in the succeeding stages. The company has 5 printing units which serve different jobs and purposes, the most critical of all being its printing press by the name of OP-18. Its selection has been done by analyzing the historical data. To better validate the causes of OEE loss, tools like Pareto analysis and FMEA should be used. Pareto analysis helps prioritize the main factors contributing to losses, while FMEA systematically identifies potential failure modes and their impacts. Using these tools would strengthen the analysis and support targeted improvements.

3.1.2 *Waste Quality*

This analysis was carried out on seven months of data. Each machine was compared to the amount of waste generated against its production quantity. It can be

TABLE 1: Production Vs Voltage

	PROD	TYPES OF JOB	WASTE %
OP-16	7	1	0.42
OP-17	9	3	2.7
OP-18	12	5	8.8
OP-19	3	3	0.3
OP-20	10	5	8.4

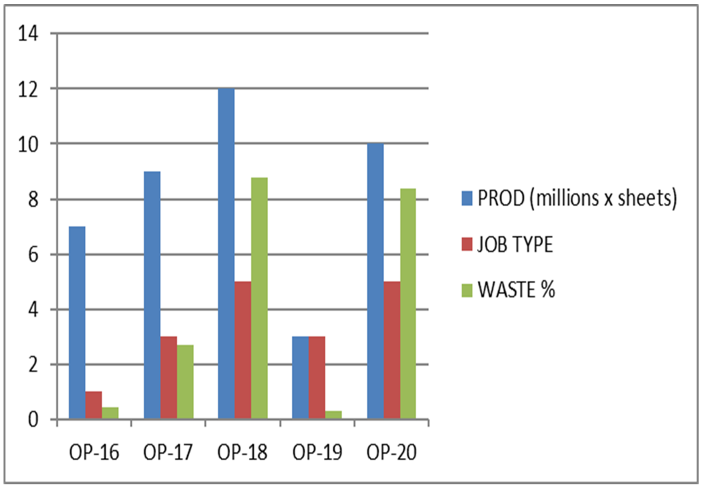


Fig. 3: Machine Vs Production, job type, waste

seen from Figure 3 extracted from Table 1 that OP-18 generates most of the waste and is engaged in the highest production as compared to other machines. This also gave an idea that OP-18 contributed to maximum output, and by reducing the amount of waste generation, the production count can be increased along with the improvement in quality (as shown in Fig. 3).

3.1.3 Downtime Analysis

The time frame was selected from Jan'15. As can be seen in Table 2, OP-18 showed the maximum downtime. Op-19 was a new setup installed in May 2015; therefore, it showed the maximum downtime in the month of May. The same can be associated with OP-20. OP-17, which could also have been selected, but most of the downtime issues were related to software errors, while our main concern was to deal with the mechanical faults. It was further learned that software errors occurred due to less command of operators while dealing with software, and as OP-17 was also a new setup, with a few trainings, this can be controlled.
Problem Definition: After downtime and wastage analysis, it was concluded that OP-18 would be selected as a sample for implementing OEE, and after achieving the desired results, the machine would be considered as the reference machine, and the same set of standards would be developed on other machines so that OEE can be implemented on the overall organization.

3.2 Phase II: Design and Implementation

3.2.1 Monitoring Phase and Time-Motion Study

Before implementation, an initial study was carried out to calculate the initial OEE value [1]. The machine was keenly monitored, which helped in understanding its working principle and capabilities. The monitoring phase included a process study and a time-motion study. The process study was carried out through machine manuals and the production team, as well as self-administered surveys. While a time motion study (TMS) was conducted job-wise, and through the following sheet template.
Each lot that would pass through the feeder was monitored and given the lot number as per sequence. The time when the lot entered through the feeder and the time it completely reached the delivery were noted. If any breakdown occurred during a single lot processing, that time was noted down, and after fixing the error, the time of restart was noted as well to calculate the total breakdown duration. The sheet counter device on the machine displayed the number of sheets passed from a single pile. Another important parameter of speed was noted down too.

Cycle per lot can be explained as:

$$= S_p/T_p \tag{3}$$

Where; S_p = No. of sheets passed in a single pile T_p = Total duration a pile took for production A sheet/minute could be obtained through

$$= Speed/(Cycle/lot) \tag{4}$$

The purpose of calculating the sheet/ minute was to evaluate which pile produced the maximum and under what circumstances. And it was found that the pile that went through zero breakdown time and worked under high speed would give the maximum sheet/minute.
The time and motion study (TMS) was conducted for 11 different jobs, and through this time motion study, production and speed loss were studied. The following outcome was generated from TMS;
Speed: The machine was working at an average speed of 8000 sheets/hour. The machine could go as high as 16000 sheets/ hour, depending upon the condition of the feeder, board grammage, and board quality.
Down time: Most common downtime errors were due

TABLE 2: Recorded downtime per machine

Machine	Jan D-T(hr)	Feb D-T(hr)	Mar D-T(hr)	Apr D-T(hr)	May D-T(hr)	June D-T(hr)	July D-T(hr)	Total
OP-16	4	0	1.5	3	4	0	0	12.5
OP-17	3	7	1.5	0	6.75	8	6.25	32.5
OP-18	7.5	3.25	12	2	13	3.5	10.25	51.5
OP-19	Uninstalled	Uninstalled	Uninstalled	Uninstalled	51	0	0	51
OP-20	Uninstalled	Uninstalled	16	6	7	3.25	1	33.25

to malfunctioning of photo cell, feeder, Board quality, environmental condition, unplanned cleaning, plate damage, etc.

On the basis of TMS, performance loss was calculated, which is demonstrated in the form of graphs as under: The machine was working under various speed limits that were dependent on the printing board, color scheme, and the machine's condition. An average speed of 13000 sh/hr was taken as ideal for normal working conditions, and production loss was calculated on this basis. The actual production average was 1 lakh sheets per day, while it could have been 1 lakh 97 thousand sheets per day if the speed had been maintained. Hence, the machine was capable of producing 50% than its actual production. This amount of production can be increased if the machine run time is high by increasing the machine's availability. It can be further concluded that sudden downtime, improper machine health, low speed, and delay in setup times were the causes of the losses illustrated below in Figure 4.

3.2.2 Data Collection and Analysis

To calculate an initial OEE value, 24-hour data collection was done over a period of two weeks. The format used can be seen in the glossary (G.4.1). Below is the data compilation from G.4.1;

Here,

Setup Time: It is the time taken to prepare the machine for the next job

Make Ready (Mr): It is the time required to adjust the color and roller axis in order to produce a quality print.

Under Maintenance (U/M): It is the time utilized in maintaining the machine due to any breakdown.

Waiting Time: It is the time spent due to the absence of any resource, let's say a new job was performed, and test sheets were printed and required approval from the quality department; therefore, the time utilized for this procedure was categorized under waiting time.

Running Time (Rt): This is the time duration taken by the machine to produce the printed sheets. It was calculated by the formula below:

Running Time + Total time − Setup time − Make Ready − Under Maintenance - Waiting

Total Time (Tt): It is the time of the overall shift that was monitored for calculating OEE.

Ideal Run Rate: It is the number of sheets the machine can produce in an hour.

$Avail = Availability$

$Perf = Performance$

$Qlty = Quality$

The formulae for AVAIL, PERF, QLTY, and OEE have been mentioned in section 2.1.

The average OEE value was 28%.

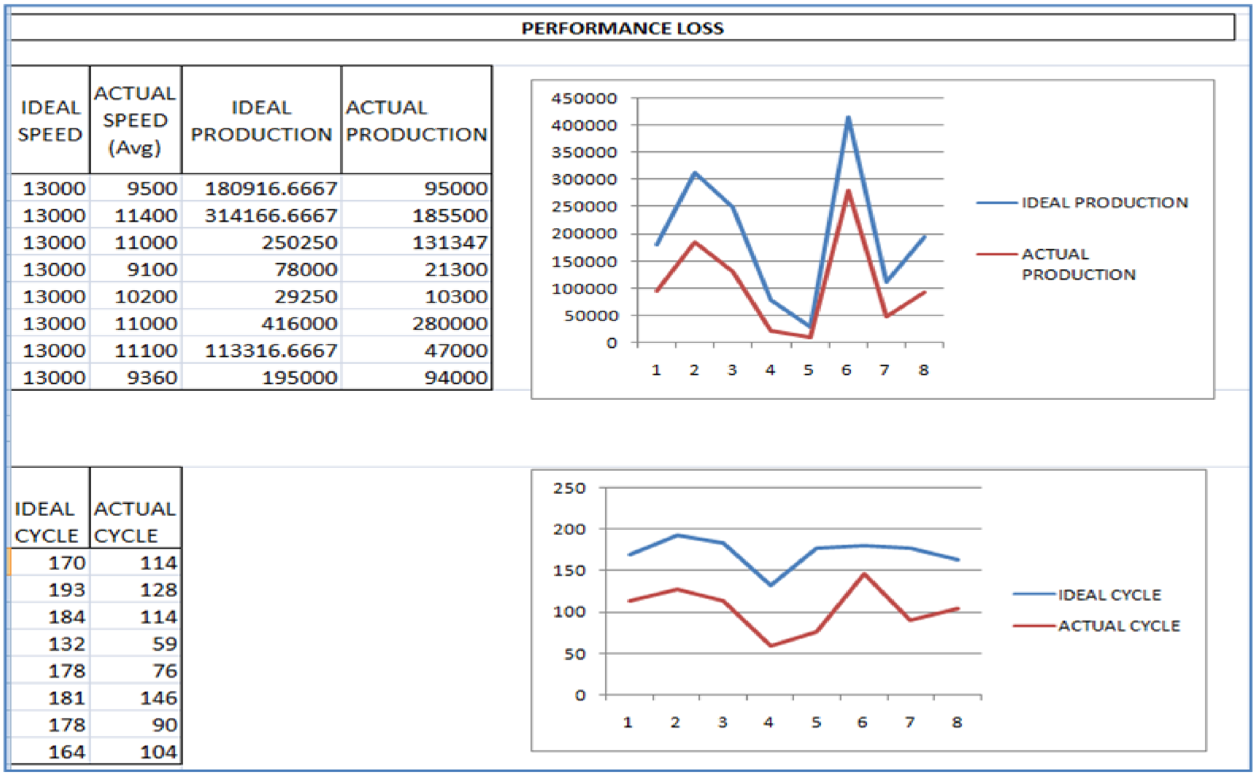
3.3 Calculation of OEE

After a time and motion study done over the period of 10 days, it was found that the OEE value was increased from 42% to 56%. The results below were derived from a time and motion study. Due to the formation of groups, the setup time was further reduced from an average of 0.96 hr per day to 0.77 hr per day. As the same nature of jobs was running back-to-back through the machine, the make-ready time also got reduced from an average of 2.3 hrs to 1.07 hr. Because of these reductions, the availability of machines increased from 83% to 90%. As the availability increased, the per day average of production became 1 hundred 98 thousand 198000 from 1 hundred and 48 thousand (148000). Since the activity of maintenance was carried on simultaneously with this GDS implementation, the performance became further better from 53% to 66% as shown in Table 4.

3.4 Results and Conclusion

Thus, after the implementation of SMED, PM, and GDS, we were able to achieve our desired aim of increasing the OEE value along with constant monitoring and control of OEE parameters that include availability and performance. Below are a few of the graphical representations that summarize the results obtained as shown in Table 5.

So, to conclude, we can say that through the implementation of SMED, GDS, and PM, the OEE


PERFORMANCE LOSS

IDEAL SPEED	ACTUAL SPEED (Avg)	IDEAL PRODUCTION	ACTUAL PRODUCTION
13000	9500	180916.6667	95000
13000	11400	314166.6667	185500
13000	11000	250250	131347
13000	9100	78000	21300
13000	10200	29250	10300
13000	11000	416000	280000
13000	11100	113316.6667	47000
13000	9360	195000	94000

IDEAL CYCLE	ACTUAL CYCLE
170	114
193	128
184	114
132	59
178	76
181	146
178	90
164	104

Fig. 4: Illustration of performance losses

TABLE 3: Initial OEE Calculation

Day	Time Break up				Production					OEE meter		
	Setup (hr)	MR (hr)	U/M (hr)	Waiting (hr)	Running (hr)	Total (hr)	Production (No. of sheets)	Ideal run rate (sheets/hr)	AVAIL	PERF	QLTY	OEE%
9-11-2015	4	5.5	1	6.5	4	21	55,150	16,000	0.19	0.86	0.95	16
10-11-2015	3.5	2.25	4	0	11.25	21	88,000	16,000	0.54	0.49	0.95	25
11-11-2015	2.75	2.25	0	0	16	21	119,220	16,000	0.76	0.47	0.95	34
12-11-2015	3.25	2.75	0.75	0	14.25	21	114,500	16,000	0.68	0.5	0.95	32
13-11-2015	5.5	4.5	0	0	11	21	71,850	16,000	0.83	0.52	0.41	0.95
14-11-2015	2	1	0.5	0	17.5	21	145,800	16,000	0.83	0.52	0.95	33
15-11-2015	0	1	1	0	5	7	47,000	16,000	0.71	0.59	0.95	40
16-11-2015	2	2	1		16	21	131,000	16000	0.76	0.51	0.95	37
17-11-2015	2	2	5.5	4.5	7	21	75,200	16000	0.33	0.67	0.95	21
18-11-2015	0	0.5	7.5	0	13	21	81,100	16,000	0.62	0.39	0.95	23

TABLE 4: OEE calculation after implementing GDS

DATE	Total Time (Hr)	Break (Hr)	Setup Time (Hr)	Make Ready (Hr)	D/T (Hr)	Run (Hr)	Total Parts	Ideal Speed	AVAIL (A)	PERF (P)	QLTY (Q)	OEE= A*P*F	OEE %
06.06.2016	24	3	0.48	1.8	0.00	18.72	190428	16000	0.89	0.64	0.95	0.54	54
07.06.2016	24	3	0.76	0.65	0.00	19.59	213730	16000	0.93	0.68	0.95	0.60	60
08.06.2016	24	3	0.55	1.2	0.80	18.45	193578	16000	0.88	0.66	0.95	0.55	55
09.06.2016	24	3	0.9	0.67	0.00	19.43	198369	16000	0.93	0.64	0.95	0.56	56
10.06.2016	24	3.5	0.56	1.5	1.00	17.44	185003	16000	0.83	0.66	0.95	0.52	52
11.06.2016	24	3	1	0.8	0.00	19.20	200945	16000	0.91	0.65	0.95	0.57	57
13.06.2016	24	3	0.67	0.5	0.45	19.38	203817	16000	0.92	0.66	0.95	0.58	58
14.06.2016	24	3	1.35	1	0.00	18.65	201059	16000	0.89	0.67	0.95	0.57	57
15.06.2016	24	3	0.8	1	0.50	18.70	198623	16000	0.89	0.66	0.95	0.56	56
16.06.2016	24	3	0.65	1.6	0.26	18.49	195395	16000	0.88	0.66	0.95	0.55	55

TABLE 5: Summarized Results

	AVAIL (%)	PERF (%)	OEE (%)
AS-IS	60	54	27.6
After SMED	78	44	33
After PM	83	53	42
After GDS	90	66	56

value has increased from 28% to 56%. There is always room for improvement, so a continuous improvement strategy will increase the OEE value further.

Future Work: The factor of quality was dependent on other factors like ink and board quality, and printing plate development, so these parameters were not experimented with and kept constant at 95%. This can be conducted as future work by varying the factors of ink, printing plate, and printing board to examine the effect on printing quality.

This work can be further modified through the installation of a DCS system monitor and control OEE

GDS can also be experimented with by creating a product mix of several products that involve almost the same color sequence. This demands a thorough analysis of the recipe for the printing of each product. After developing the group of product mix, one can feed the group list in the control panel of the machine so that the printing operation can run automatically.

To sustain improvements from SMED, Planned Maintenance, and Group Dependent Scheduling, long-term monitoring using SPC and KPIs is essential for tracking performance and detecting issues early. Regular review of these metrics guides continuous improvement efforts.

Limitation: This work is limited to the printing industry that uses Offset printing technology. This work involves manual data collection, which demands accuracy and time; therefore, it is recommended to use software to calculate OEE, as this will create ease, maintain data accuracy, and consume less time and effort.

References

[1] W. Kaydos, Operational Performance Measurement: Increasing Total Productivity. Boca Raton, FL: CRC Press, 2020.

[2] S. Nakajima, Introduction to TPM: Total Productive Maintenance. Cambridge, MA: Productivity Press, 1988.

[3] F. Kechaou, S. A. Addouche, and M. Zolghadri, "A comparative study of overall equipment effectiveness measurement systems," Production Planning Control, vol. 35, no. 1, pp. 1–20, 2024.

[4] A. K. Gupta and R. K. Garg, "OEE improvement by TPM implementation: a case study," Int. J. IT, Eng. Appl. Sci. Res., vol. 1, no. 1, pp. 115–124, 2012.

[5] R. Iannone and M. E. Nenni, "Managing OEE to optimize factory performance," in Operations Management. London, U.K.: IntechOpen, 2013.

[6] A. Sohal, J. Olhager, P. O'Neill, and D. Prajogo, "Implementation of OEE—issues and challenges," in Competitive and Sustainable Manufacturing Products and Services, pp. 1–8, 2010.

[7] T. Herlevi, Improvements in Reliability of Production Machines: A Maintenance Perspective, 2024.

[8] A. K. Tilkar and R. A. Nagaich, "A case study approach to productivity enhancement and calculation of overall equipment effectiveness."

[9] A. S. Vairagkar and S. Sonawane, "Improving production performance with overall equipment effectiveness (OEE)," Int. J. Eng. Res. Technol., vol. 4, no. 2, pp. 700–704, 2015.

[10] N. C. Maideen, S. Sahudin, N. M. Yahya, and A. O. Norliawati, "Practical framework: implementing OEE method in manufacturing process environment," in IOP Conf. Ser.: Mater. Sci. Eng., vol. 114, no. 1, p. 012093, IOP Publishing, 2016.

[11] S. Molla, M. R. Hasan, A. A. Siddique, and I. M. Siddique, "SMED implementation for setup time reduction: a case study in the electronics manufacturing landscape," Eur. J. Adv. Eng. Technol., vol. 11, no. 1, pp. 1–15, 2024.

[12] S. Shingo, A Revolution in Manufacturing: The SMED System. London, U.K.: Routledge, 2019.

[13] B. Ulutas, "An application of SMED methodology," World Academy of Science, Engineering and Technology, vol. 79, no. 7, pp. 100–103, 2011.

[14] R. I. McIntosh, S. J. Culley, A. R. Mileham, and G. W. Owen, "A critical evaluation of Shingo's SMED (Single Minute Exchange of Die) methodology," Int. J. Prod. Res., vol. 38, no. 11, pp. 2377–2395, 2000.

[15] G. F. I. Toki et al., "Single Minute Exchange Die (SMED): a sustainable and well-timed approach for Bangladeshi garments industry," Cleaner Eng. Technol., vol. 12, p. 100592, 2023.

[16] H. Soltanali, M. Khojastehpour, and J. Torres Farinha, "An improved risk and reliability framework-based maintenance planning for food processing systems," Qual. Technol. Quant. Manage., vol. 20, no. 2, pp. 256–278, 2023.

[17] L. Xia, Y. Liang, J. Leng, and P. Zheng, "Maintenance planning recommendation of complex industrial equipment based on knowledge graph and graph neural network," Reliability Eng. Syst. Safety, vol. 232, p. 109068, 2023.

[18] Z. Ren, A. S. Verma, Y. Li, J. J. Teuwen, and Z. Jiang, "Offshore wind turbine operations and maintenance: a state-of-the-art review," Renew. Sustain. Energy Rev., vol. 144, p. 110886, 2021.

[19] S. Gawiejnowicz, "A review of four decades of time-dependent scheduling: main results, new topics, and open problems," J. Scheduling, vol. 23, no. 1, pp. 3–47, 2020.

[20] A. Kusiak, "The generalized group technology concept," Int. J. Prod. Res., vol. 25, no. 4, pp. 561–569, 1987.

[21] D. Ross, D. Darto, A. Iswantoko, and P. Kurniawan, "Implementation of group technology in the manufacturing process of disk mill machine," Transmisi, vol. 20, no. 1, pp. 34–44, 2024.