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IMPROVING THE OVERALL EQUIPMENT EFFECTIVENESS OF SHEET-FED OFFSET PRINTERS: A CASE STUDY

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ABSTRACT

This study investigates a framework for enhancing the Overall Equipment Effectiveness (OEE) of sheet-fed offset printers, focusing on the packaging sector. The research explores the understanding and implementation of OEE valuation within this context. Through a specific case study, the OEE value is 22%, with contributions from Availability, Performance, and Quality rates at 41%, 58%, and 94%, respectively. These findings underscore a substantial deviation from the world-class standard of 85%, indicating significant room for improvement. Based on Six Big Losses (SBL) and Cause and Defect diagram analysis, workers' lack of knowledge and skill and ineffective management methods are critical contributors to low OEE rates. In response, an action plan is proposed to improve OEE, aiming to reduce time losses by approximately 60% and achieve a standard OEE value. This research offers valuable insights into optimizing the efficiency of sheet-fed offset printers, offering practical strategies for enhancing productivity and competitiveness in the printing industry.

Keywords: Offset printing; printing process; overall equipment effectiveness; big six losses; OEE improvement.

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INTRODUCTION

The offset printing sector has played a pivotal role in the publishing, advertising, and packaging domains, offering a cost-efficient and high-caliber solution for mass-producing printed materials. Current offset printers have applied advanced technology with precision engineering and reliability, significantly enhancing efficiency and productivity in printing operations globally.

Nevertheless, printer operators often face challenges that obstruct optimal performance, such as unexpected downtime, below-standard quality, or inefficient production processes. Effectively addressing these issues requires a comprehensive understanding of the factors influencing equipment effectiveness and implementing targeted improvement strategies.

One widely adopted method for evaluating and improving equipment performance is OEE (Prakash *et al.*, 2019), in which equipment utilization is assessed by availability, performance, and quality rates (Nakajima, 1988). Organizations can enhance manufacturing performance by benchmarking OEE values, allowing them to track advancements effectively (Gupta & Vardhan, 2016). However, they must grasp the OEE concept and its constituent elements to identify the OEE value correctly. There have been inconsistencies in different aspects of OEE, including interpretation, calculation, loss definition, ideal cycle time, treatment of planned downtime and minor stoppages, and definition of an optimum overall value, which can lead to misunderstandings in its application (Baluch *et al.*, 2012). Therefore, the current OEE has significantly expanded beyond its origins to address these limitations. OEE appears differently in various business sectors and industries (Prakash *et al.*, 2019). Despite these advancements, a systematic approach/framework and guiding steps for OEE implementation are lacking (Ahmed En-Nhaili, 2016)

The printing industry distinguishes itself from other manufacturing sectors primarily due to its variable shift times and unique operational structures (Özveri *et al.*, 2016). A printing process involves multiple stages: preparation, adjustment, and production of prints, each conducted with a set of printing plates (plates installed once on the printer). This process can be repeated once or many times a day. However, the time required to execute each stage of each printing process differs greatly depending on the product characteristics, printing method, and printing run. Furthermore, there is frequently an overlap between preparation time, pre- and post-printing cleaning, and transitioning between printing processes. Hence, identifying planned or unplanned periods when implementing OEE is unique to each printing facility.

On the other hand, the printer's run speed often depends on the required quality under specific conditions (Nam, 2019). Printers also require acceleration or deceleration processes to achieve the required speeds. These indicate the presence of an optimal speed rather than a maximum speed. Consequently, challenges are encountered while implementing the OEE calculation in the examined printing facility. The application of OEE for equipment and printing systems necessitates a clear understanding of the OEE concept and its definition of constituent elements.

In the literature, studies evaluating OEE for printers are minimal, and the unique characteristics of the printing process are almost overlooked (Kataka, 2018; Irawan, 2022; Zahoor, 2017). Some authors (Kumar, 2014; Özveri, 2016) have attempted to incorporate specific printing conditions into OEE calculations for newspaper

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printers. However, further research is needed for other printing technologies.

The observed OEEs of actual printing presses significantly fall below world-class standards (85%), with an average OEE ranging from 20 - 60% (Kumar, 2014) (Kataka, 2018). These reductions in OEE likely come partly from differences in the OEE calculation method, as discussed above. However, the results imply that printers are much less effective. Since printing processes are complicated and heavily dependent on numerous external variables (Kataka, 2018), there is a clear need for OEE improvement frameworks tailored to the printing sector, which is currently lacking in the literature.

This study is a refinement and modification of elements of the general OEE in a specific case, a typical sheet-fed offset printer in the packaging sector. The paper also establishes an OEE improvement framework that offers steps for OEE improvement implementation. This framework will be the reference for the OEE implementers in printing houses.

EXPERIMENTAL

Equipment and Workflow

The current study selected a sheet-fed offset printing machine, KBA Rapida 105-6+L, from a typical packaging company in Hanoi, Vietnam. The machine specification and production capacity are listed in Table-1 (KBA, 2017).

Table-1. KBA Rapida 105-6 printer specifications.

Max. sheet format	**720 ×1050 mm**
Print format	710 × 1040 mm
Substrate thickness	0.06 – 0.7 mm
Max. production speed	16,000 sheets/h
Printing unit	6
Fully automatic plate change	✓
CleanTronic washing systems	✓
VariDry dryer systems	✓
ErgoTronic console with TouchTronic interface	✓
CIP3	✓
Pile height	Feeder 1,300 mm Delivery 1,200 mm
Plate and blanket dimensions	Plate size 795 x 1050 mm Blanket size 860 x 1060 mm
Year of Manufacture	2018

Offset printing is an indirect printing technology in which the ink is initially transferred from the printing plate onto the blanket (an intermediate carrier) and then onto the substrate (often paper). The principle of offset printing is shown in Figure-1.

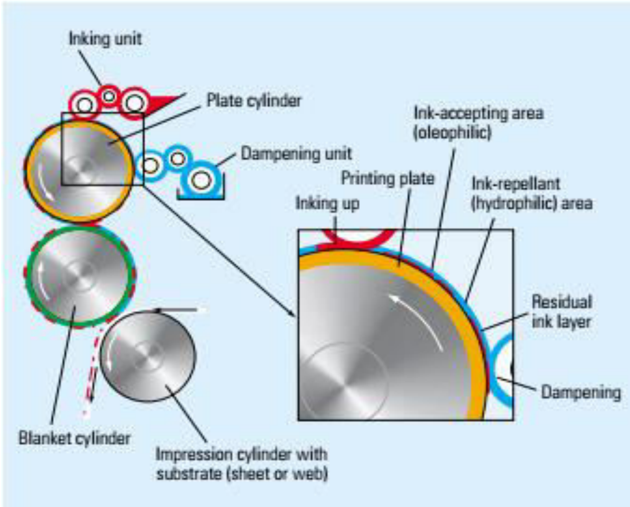

Figure-1. Offset printing schematic. Source: (Kipphan, 2001).

The printing plate combines the printing and non-printing areas on one level. The printing areas are oleophilic and ink-accepting. The non-printing areas are hydrophilic and water-accepting. The printing quality depends on an ink-water balance obtained on the plate during printing.

Printing products: Box packages made of ivory and duplex paper from 300 - 400 g/m2. The products are one-sided prints with images of 4 - 6 colors. Each print runs one time through the printer.

Printing process: A typical production of printed products is presented in Figure-2.

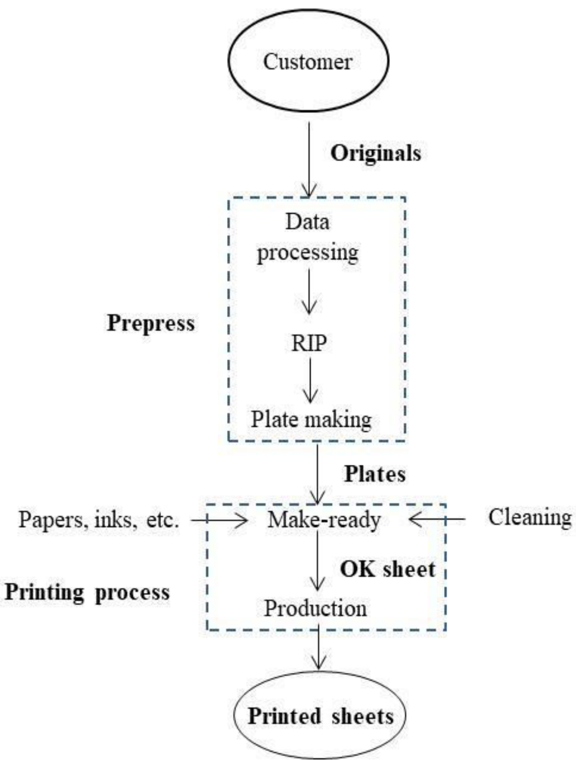

Figure-2. Production flow of printed sheets.

The printing process includes two main steps as follows:

Make-ready: the preparation for starting a printing production. This work includes checking the job ticket, checking materials, setting up the sheet control system, water fountain, ink system, inking up the roller, installing the plate, adjusting the ink-water balance, image registration, and image quality. The work is completed when the first good quality product is obtained and is approved as the OK sheet.

Printing production: producing printed sheets with the required quantity after getting the OK sheet.

Each printing process corresponds to an installation of a printing plate set. Thus, a printed sheet can be created by one or several printing processes depending on the original and printer characteristics.

One or more printing processes can occur in a day, but the printer must be cleaned before each printing process, and the original materials must be ready. A typical working day in the investigated printing company is shown in Figure-3.

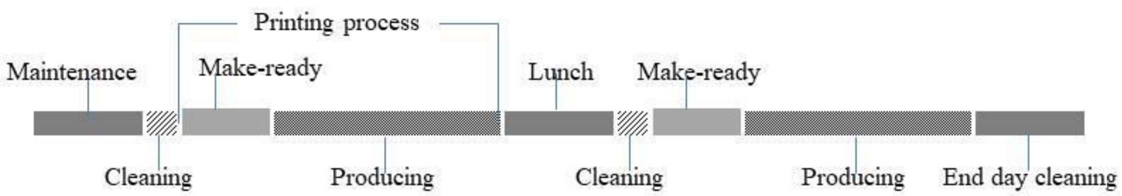

Figure-3. A typical working day of the press in the printing company.

OEE Improvement Framework

In our study, five steps were carried out to improve the OEE, as shown in Figure-4.

1. Data collection: Collect real-time data on activities carried out in one month of 2023.
2. OEE calculation: OEE value was computed from the collected data
3. Six Big Losses (SBL) analyses: categorize the losses that reduce the OEE.
4. Cause and effect analysis: Understand the core issue of main losses among SBL during the production
5. Creating an action plan: improve the OEE value.

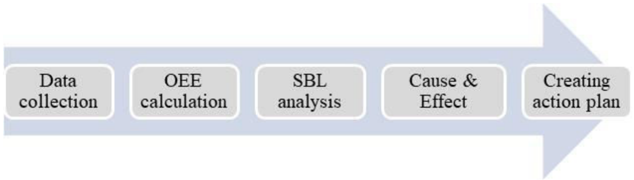

Figure-4. OEE Improvement Framework.

OEE Calculation

OEE is calculated following the formula of Nakajima (1988). The element is redefined to suit the printing process. The OEE timeline is shown in Figure-2.

$$\text{OEE} = \text{Avaiability} \times \text{Performance} \times \text{Quality} \quad (1)$$

The Availability (A) is calculated as:

$$A = \frac{(\text{Loading time} - \text{downtime}) \times 100}{\text{Loading time}} \quad (2)$$

Loading time is the working time, not including the planned maintenance, cleaning, and rest times. The cleaning time before the printing process is also considered the planned cleaning. In the investigated case, the maintenance is half an hour at the beginning and the end of the working day, the rest for lunch is 1 hour, and the average cleaning time/shift is 0.1 hour.

Downtime is when the printer cannot function or work.

Performance (P) is calculated as:

$$P = \frac{\text{Theoretical cycle time} \times 100}{\text{Actual cycle time}} \quad (3)$$

Theoretical cycle time - the minimum time the printer can expect to produce a printed sheet in optimal circumstances. This depends on specific printing conditions such as printing targets, substrates, inks, and machine status. Thus, the theoretical cycle time is often under the designed one (maximum speed). Our printer's ideal cycle is about 70% of the maximum speed (Nam , 2019), i.e., 1/11000 hour/sheet.

Actual cycle time - The real production time to produce a printed sheet can be calculated as follows:

$$\text{Actual cycle time} = \frac{\text{Operating time}}{\text{Process amount}} \quad (4)$$

Operating time is the printing production time used to produce printing products.

$$\text{Operating time} = \text{Loading time} - \text{downtime} \quad (5)$$

Process amount is the number of printed sheets made during the operating time (counted in the printer).

Quality (Q) is calculated as

$$Q = \frac{\text{Accepted amount} \times 100}{\text{Process amount}} \quad (6)$$

The accepted amount is the number of good-quality printed sheets delivered to the following stages. All the non-accepted printed sheets, even good quality ones, are considered quality loss.

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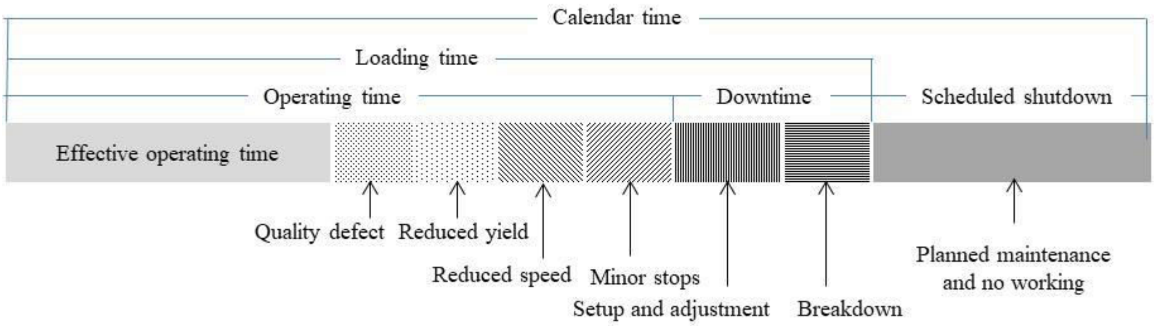

Figure-5. OEE and BSL timeline.

SBL Calculation

The SBL was conducted after calculating the OEE to find the most significant loss that should be eliminated from the manufacturing process (Muñoz-Villamizar, 2018). The SBL formulas used in the paper can be seen in equations (7) - (12). The descriptions of the items are given in Table-2.

$$\text{Breakdown loss} = \frac{\text{Breakdown time}}{\text{Loading time}} \tag{7}$$

$$\text{Set up and adjustment loss} = \frac{\text{Set up and adjustment time}}{\text{Loading time}} \tag{8}$$

$$\text{Reduce speed loss} = \frac{\text{Process amount}\times(\text{Theoretical cycle time} - \text{Actual cycle time})}{\text{Loading time}} \tag{9}$$

$$\text{Idling and minor stoppage loss} = \frac{\text{Stop time}}{\text{Loading time}} \tag{10}$$

$$\text{Quality defect loss} = \frac{(\text{process amount} - \text{good amount})\times\text{Theoretical cycle time}}{\text{Loading time}} \tag{11}$$

$$\text{Reduced yield loss} = \frac{(\text{good amount} - \text{accepted amount})\times\text{Actual cycle time}}{\text{Loading time}} \tag{12}$$

Table-2. SBL description.

No	Loss	Description
1	Breakdown	Equipment and tooling failure
		Unplanned maintenance
		Unexpected shutdowns: waiting time for material shortages or material changes, changeover time between shifts.
2	Setup and adjustment	Make-ready
		OK sheet approvals
3	Reduced speed	The lost time is caused by the press running at a lower speed (than the ideal speed) due to substandard materials, complicated targets, or inefficient operation.
4	Idling and minor stoppage	Minor issues take less than 10 minutes during the printing process. The other longer errors are taken into breakdown
		Cleaning or quick inspection during the printing process.
5	Quality defect	Defect printed sheets are produced during production after the OK sheet is created. Bad quality amount = produced amount - good amount
6	Reduced yield	Good printed sheets are rejected as exceeding the required quantity

Cause and Effect Analysis

The cause and effect diagram (the fishbone diagram) determines the causes of the most considerable loss among the BLS analyzed above. The factors contributing to this diagram are often divided into the 6Ms in the manufacturing world: workforce, machine, method, material, measurement, and mother nature (Holifahtus Sakdiyah *et al.*, 2022).

RESULTS AND DISCUSSIONS

OEE and SBL Value Identification

The OEE calculation for the printer in a month is reported in Table-3.

Table-3. OEE identification.

Loading time (h)	**365**	41%	22%
Operating time (h)	149		
Ideal speed (sph)	11000	58%	
Actual speed (sph)	6371		
Process amount (sheet)	956854	94%	
Accepted amount (sheet)	902692		

The OEE value of 22% is significantly lower than the world-class standard of 85% (Muñoz-Villamizar *et al.*, 2018). It is also lower than other reported equipment in the printing sector. It shows that Availability ranks lowest among the three factors (41%). As shown in Table-4 and Table 5, the downtime mainly comes from make-ready (18.3%), waiting for material changes (21.7%), waiting for custom approval (15%), and minor stops (16%).

Table-4. SBL identification.

	Loss	Time (h)	Loss value (%)
A	Breakdown (B)	93	25.5
	Setup & adjustment (S)	122	33.3
P	Reduced speed (R)	5	1.4
	Minor stop (M)	58	16.0
Q	Defect (D)	4	1.2
	Reduced yield (Y)	1	0.3

Table-5. Main losses summary.

	Loss	Frequency	Time (h)	Loss value (%)
B	Printer errors (B8)	8	14	3.8
	Waiting for material changes (B28)	28	79	21.7
S	Make ready (S265)	265	67	18.3
	Waiting for approval (S25)	25	55	15.0
M	Cleaning during process (M738)	738	55	14.9
	Operation errors (M112)	112	3.9	1.1

The result also indicates a problem without the machine engine. The printer errors are only 3.8%, and the printer did not cause minor stops. The OEE quality rate (94%) is equivalent to the standard, so it will not be examined in the following sections.

Roots of the Low Value of OEE

Table-6 identifies the errors that cause breakdown, adjustment, and minor stoppage loss errors. The error data classification is recorded in the company's collected data.

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Table-6. Error summary.

Loss	Error	Frequency	Time (h)	Loss value (%)
B28	Bad quality papers (Changing papers)	7	16	4.4
	Incorrect color inks (Rematching inks)	6	10	2.8
	Prepress errors (Remaking plates)	15	53	14.5
S265	Adjustment time for each shift	237	60	16.4
	Additional adjustments	28	7	1.9
S25	Waiting for customer approval	25	55	15.0
M738	Bad quality papers (hickeys, doubles)	229	20	5.4
	Ink-water balance errors	509	35	9.5
M112	Installed wrong plates	2	0.2	0.1
	Ink-water balance errors	110	4	1.0

The causes of errors leading to decreased equipment efficiency are classified into Man, Materials, Method, and Others, presented in a fishbone diagram (Figure-6).

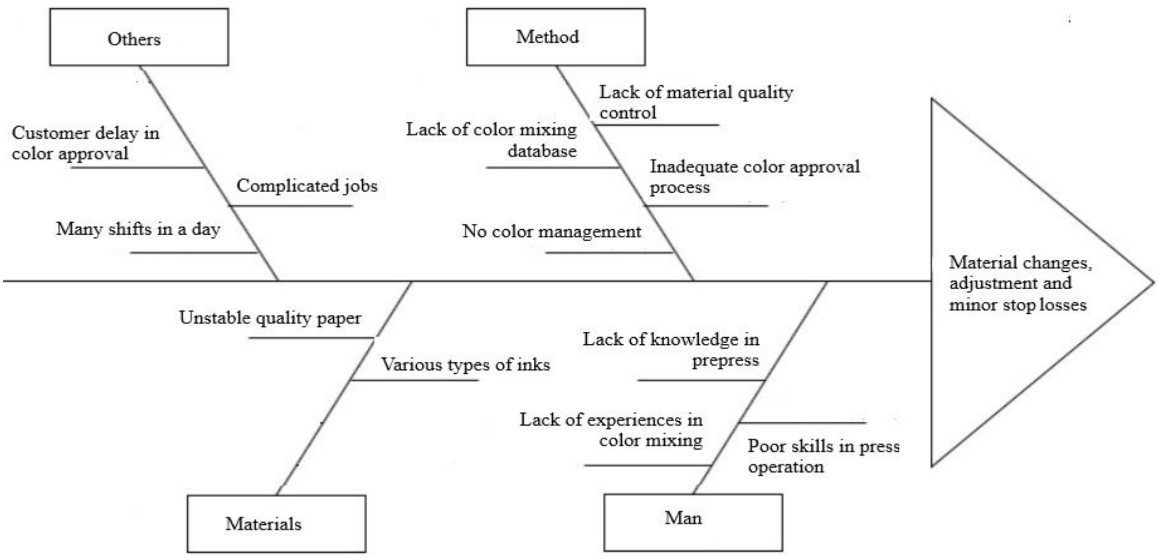

Figure-6. Fishbone diagram of material change, adjustment, and minor stop losses.

Man

It can be observed that the majority of errors, accounting for time losses of 46.2%, are related to the skill and expertise of three worker groups. These are color mixing technicians, prepress workers, and press operators.

- Prepress errors, such as incorrect print option specifications relevant to the worker's knowledge, cause 14.5% time loss. These errors also make the adjustment of the printing process more difficult.
- Color mixing errors occurred due to inexperienced workers, leading to a time loss of 2.6%.
- With the total make-ready time of 60 hours for 237 printing shifts, a make-ready time is approximately 14 minutes/shift, which is over 40% higher than the typical time for a 6-color sheet-fed offset press with preset ink key systems (CIP3). The 40% loss of time equal to 24 hours (6.6%) is attributed to operator issues. In addition, the press operator's skill-related errors, such as unstable ink-water balance, contribute to 10.5% of time losses.

Methods

There are three significant issues in the technical execution method at various production stages.

- No color management

Color management is a solution that ensures consistent color reproduction across devices in the workflow, such as monitors, proofing machines, and offset printers (Sharma, 2018). No color management can lead to incompatible output data with the press characteristics, resulting in time-consuming adjustments or data re-exporting. Besides, without color management, the proofing options, such as soft or digital copies, are hard to apply due to technological differences between the proofing systems and the offset printers. Thus, it results in significant time losses related to setup, adjustment, and waiting for approval.

- Inadequate color approval process

In the investigated company, the customer color approval occurs on the OK sheet in the printing room or at the customer's place. In both cases, the waiting time is prolonged. When color approval occurs at the printing room, customers must travel, whereas sending samples to them results in even longer wait times for feedback. Moreover, the color-checking method based on visual inspection is time-consuming.

- Lack of color mixing database

The company has used software, printing simulation tools, and modern color measurement devices to mix colors. However, the database only has about 20% accurate formulas; most colors require adjustment based on experience. This reality results in inaccurate mixed colors and prolonged setup time on the printing press.

- Lack of material quality control

There is a lack of quality standards for materials applied to suppliers and inspections. This causes instability throughout the entire system, from prepress to press.

Materials

- Unstable quality papers:

Inconsistent paper quality, such as dust or uneven color, complicates machine operation and inaccurate color reproduction. Paper-related errors, such as hickeys or double sheets, contribute to losses of up to 5.4%, with additional waiting time for paper change (4.4%). Moreover, paper indirectly affects setup and adjustment time.

- Various printing inks:

The company uses different ink brands for color mixing, resulting in inaccurate mixed colors and complicating printing press setup and operation.

Other factors

- Complicated jobs

The printing jobs, which involve packaging products requiring uniform colors and numerous new designs with small quantities (4000-5000 copies), pose challenges for inexperienced printers.

- A large number of shifts

The adjustment time is significantly increased with a relatively high number of daily job changes (average ten shifts in a day).

- Customer delay in color approvals

Customers sometimes took longer than expected to approve colors for subjective reasons.

Action Plan to Improve OEE

Based on the reasons pointed out above, an action table has been proposed to address core issues such as people, methods, and materials (Table-7). This plan aims to eliminate nearly 60% of lost time, including errors related to materials (zero), operations in prepress and press (minimum), waiting for materials (zero), and customer approvals (minimum). An OEE of above 82% is expected.

Table-7. Action plan for improving OEE.

Factor	Problems	Action plan
Man	Lack of knowledge and skill in prepress, press, and color matching	Group training: + Color management + Output through the color profile and proofing + Standardization + Color mixing
Material	Unstable raw materials	+ Checking paper characteristics, making periodic controls
Method	Failure to apply practical quality management tools	Apply the management methods: + Color management + Proofing options + Printing quality control Building the color database for color matching

CONCLUSIONS

The research has provided insights into understanding and implementing OEE evaluation for printing equipment. In the specific case studied, the OEE value obtained is 22%, with contributions from Availability, Performance, and Quality rates at 41%, 58%, and 94%, respectively. This OEE value falls significantly below the world-class standard of 85%. The low Availability and Performance rates are attributed to a lack of knowledge and skill among workers and ineffective management methods. An action plan for improving OEE has been proposed to reduce time losses by approximately 60% and achieve a standard OEE value.

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