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# A new approach for effective productivity management of newspaper printing press

**ABSTRACT**

*Within the modern commercial printing press, a common problem is the efficient management of the maintenance of different machines of newspaper printing press. If Effective Maintenance Management is applied, productivity of the machines can be increased by reducing breakdown time of the machine. Productivity Management is an organizational framework that helps machines to improve productivity. Productivity of a machine is dependent on the failure probability which can be controlled by technical and management actions. The present investigation is established by the analysis of productivity, effectiveness and failure probability on the basis of Pareto Analysis. Pareto chart is also developed to understand the actual scenario where highest priority events are sequentially arranged. It has been observed that the web-offset printing machine has the highest productivity and effectiveness with less failure probability while the exposure unit has the highest failure probability having low productivity and effectiveness. Based on the reduction of probability of failure to meet the acceptable criteria, further maintenance planning can be suggested. This approach confirms that productivity and effectivity of the machines of newspaper printing press can be increased by considering consequences of the machines and their corresponding failure assessments.*

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Total productivity, partial productivity, overall effectiveness, failure probability

## Introduction

Productivity performance plays a vital role in manufacturing industry and it has been important aspects for improving the quality of finished product as well as reputation of manufacturing house. Recently, in developing country like India, the issue of a improvement of partial productivity and total productivity has become most important aspects for any manufacturing house.

There are various types of machines needed for printing press with advances in technology. During the printing process there exists different types of scraps and wastages in the press that need to be handled and minimized. This is where requirement of productivity and profit measurement exists. The print production house is one of the labor intensive manufacturing firm that contribute to economy growth of India.

Productivity is the important factor for a press to achieve maximum outputs in required time with less cost. Machine productivity is the measurement of a machine's proficiency in converting the raw inputs into useful products. In the present investigation an attempt has been made to make a quantitative assessment of productivity, effectiveness and utilization of several machines used in a commercial newspaper printing press.

In this press one web-offset printing machine and three prepress equipments are examined for the study. Partial and total productivity of different machines are measured with the help of selected resources such as labor input, capital input, material input and miscellaneous inputs etc. Productivity improvement has become a important issue (factor) for policy makers, strategic planner and top level management as it is becoming a key factor affecting the overall effectiveness of press/produc-

tion house. It is observed that productivity and effectiveness of an equipment can be increased by implementing Effective Maintenance Management (EMM) of machines in a newspaper printing press. Productivity is a Key-Metric to measure the efficiency of any costly equipment for the implementation of Total Productivity Maintenance (TPM) philosophy.

The target is the highest productivity of a costly equipment for the improvement of effectiveness and best possible return of the facilities. Based on the existing problems of machines of newspaper printing press, a proposed methodology has been suggested by conducting an in-depth analysis of variation of different input costs as well as production time and breakdown time.

## Literature Review

Some works in the domain of measurement of productivity and effectiveness of manufacturing machines have been done by various researchers. A framework for productivity analysis of maintenance management had been studied (Kutucuoglu et al., 2001) by using performance measurement system. In another study (Hernandez et al., 2006), different performance parameters like overall effectiveness, big losses had been evaluated for a manufacturing process. Several invisible losses like speed loss, startup loss etc. had been studied in detail (Olivier, 2007) to implement total productive maintenance in manufacturing and assembly industry.

A systematic process planning and implementation of robust framework of maintenance had been successfully applied (Sivakumar & Saravanan, 2011) for the increment of both partial productivity and total productivity in textile fabric industry. Analysis of productivity of printing machines had been studied (Kumar, Varambally & Rodrigues Lewlyn, 2012) and later overall effectiveness of printing machines had also been measured in a study (Kumar, Shetty & Rodrigues Lewlyn, 2014). Different metrics like Productivity, Utilization, Uptime factors etc. for printing and manufacturing industry were analyzed (Spencer, Fiasconaro & Sahay, 2014) by using a software. It is seen that overall effectiveness-based analysis on Radio-Frequency Identifier (RFID) based automatic process had shown more accuracy than manual process of tool management (Dovere, Cavalieri & Ierace, 2017).

OEE framework had been applied successfully in different sustainable manufacturing industries (Maideen et al., 2015) (Poorya, Aydin & Majid, 2018). The effect of non-added value (NVA) activity related to maintenance throughout the year in manufacturing industry will also act as a important parameter to balance the efficiency measurement for productivity improvement (Wardah et al., 2018). In a cement manufacturing firm, a pilot study (Rabindra & Purushottam, 2019) had been conducted on the basis of measurement of partial productivity and total productivity. Oni Jaya Motor in Indonesia controlled their production efficiency by daily monitoring of effectiveness and reduced their six big losses by countering the most influencing losses like set up and adjustment of 29.8%, Reduced Speed Loss of 25.6% and Breakdown Loss of 21.3% as well with monthly improvement scores (Setyawan et al., 2021).

Overall effectiveness (OEE) metrics has now been used universally for the identification of potential of production capacity even in multi-productive system by some researchers (Corrales et al., 2020; Li, Liu & Hao, 2021). Also, in the domain of small-medium scale enterprise or any automotive industry a novel approach has been developed which is offering the world with high class availability, performance, quality, OEE, TEEP, productivity etc. (Tayal et al., 2021).

However, total factor productivity (TFP) plays a key role for the development of technological progress in industry and recently it is shown that TFP of high tech industries in China is upward by applying Malmquist and Hicks-Moorsteen indices (Chen, Liu & Zhu, 2022).

In the present investigation a new frame work has been designed on the basis of production time, number of failures and its associated costs for the measurement and improvement of Total Productivity (TP) along with the overall effectiveness and utilization to understand the exact Return on Investment (ROI) of the newspaper printing press.

## Materials and Methods

### Productivity

Print production requires various material and immaterial inputs to produce finished outputs. It needs some measure to track its inventory, production status and profit analysis. Here the concept of productivity arises for measuring various inputs in terms of cost or time etc. The production function represents production performance and productivity to improve final outputs. So, Productivity is defined as a ratio of aggregate volume of output measure of actual product to a volume input measurement of consumed resource in making the product or providing the service.

Productivity in terms of time ($|TP|_{Time}$) is also measured by the ratio of actual production time or runtime to potential production time. Uptime is the ratio of actual production and idle time to the total available production time (which includes the runtime, breakdown time, repair time, idle time etc. but excludes schedule breaks i.e. all available time per shift/day/week).

Productivity and uptime are expressed by Equations 1&2. Potential production time is nothing but the usable time period of operation which includes runtime and downtime but excludes idle time (Spencer, Fiasconaro & Sahay, 2014).

$$|TP|_{Time} = \frac{(\text{Actual production time (or runtime)})}{\text{Potential production Time (or planned production time)}} \quad (1)$$

$$\text{Uptime} = \frac{(\text{Actual production time} + \text{Idle time})}{\text{Available all time per shift or day or week}} \quad (2)$$

To understand the better scenario of productivity in terms of cost, Total-Factor Productivity (TFP) is used to access the quick commercial productivity in the industry. It is the ratio of net output and total factor input where net output is the total output excludes intermediate purchased goods and services and total factor input includes labor inputs & capital inputs as shown in Equation 3. But the limitation of TFP is that net output does not consider the efficacy of production system in a proper way as inputs like material, energy, services are ignored.

Multi-factor productivity (MFP) is introduced on the basis of soft factors like people, organizational system, work method, management styles which is easily changeable. It can use instantaneous needful inputs and can easily excludes the non-required inputs to monitor daily productivity index for better understanding of performance rate with available resource as shown in Equation 4.

$$\text{Total factor productivity (TFP)} = \frac{\text{Net output}}{\text{Total factor input}} = \frac{\text{Total output} - (\text{Labour, material, energy, service \& } \textit{other inputs})}{\text{Labour \& } \textit{capital input}} \quad (3)$$

$$\text{Multi-factor productivity (MFP)} = \frac{\text{Total output}}{\text{Total input excludes specified parameter (like capital inputs etc.)}} \quad (4)$$

The important mathematical expression of total productivity (TP) along with its supporting factor like partial productivity (PP) and weightage factor are given in Equation 5, 6 and 7. Therefore, total productivity is the ratio of total aggregate output (Oi) to aggregate input (Ii) of $i^{th}$ product/day/week/event. Also, "$I_i$" is the summation of all the individual $j^{th}$ factor of input(where, j: {material (M), energy (E), human (H), capital (C), maintenance & other expenses (X) etc.}). Partial productivity (PP) index is the ratio of total output (Oi) to one class of input ($I_{ij}$) and weightage factor ($W_{ij}$) is the ratio of instantaneous one factor input ($I_{ij}$) to the total aggregate input (Ii) i.e. "$\sum$ Iij". Also profit% (π%) is related to total productivity is shown in Equation 8. It is important to note that for 100% productivity, profit is zero and if productivity is less than or more than 100% then we can calculate the loss and profit margin.

$$TP = \frac{\text{Total aggregate output (Oi)}}{\text{Total aggregate input (Ii)}} = \text{Partial productivity (PPij)} \,.\, \text{Weightage (Wij)} \quad (5)$$

$$PP_{ij} = \frac{\text{Total aggregate output (Oi)}}{\text{One factor input (Iij)}} \quad (6)$$

$$W_{ij} = \frac{\text{One factor input (Iij)}}{\text{Total aggregate input } (\sum_j \text{Iij})} \quad (7)$$

$$\pi\% = \frac{(Oi - Ii)}{Ii} .100\% = (TP - 1) .100\% \quad (8)$$

The productivity can also be considered as an important dimension for introducing TPM program along with OEE in the printing and other industry for production audit and production performance with the special reference to profit percentage.

Also, from the above study we can re-estimate the Combined overall press equipment productivity (COPEP) i.e. the summation of all the useful press equipment productivity (where k stands for number of equipment considered) as shown in Equation 9 to understand the total press expense in terms of total productivity.

$$COPEP = \sum_k TP = \frac{|\text{Total output}|_k}{|\text{Total input}|_k} = \frac{|Oi|_k}{|Ii|_k} \quad (9)$$

## TEEP

From the theory of overall equipment efficiency (OEE) and utilization factor of a particular equipment, total effective equipment performance (TEEP) is derived.

TEEP directly deals with the actual production scenario of an effective time taken for usable output from the available total time for production per shift day or week or month. By definition TEEP is the product of OEE and Utilization Factor as shown in Equation 10.

$$TEEP = OEE \,.\, \text{Utilization Factor} = (\text{Availability} \,.\, \text{Performance} \,.\, \text{Quality}) \,.\, \text{Utilization Factor} = \frac{(\text{Good pcs}) \,.\, (\text{Cycle time})}{(\text{Total planned production time})} \cdot \frac{(\text{Total planned production time})}{(\text{Available all time per shift or day or week})} = \frac{(\text{Good pcs}) \,.\, (\text{Cycle time})}{\text{Available all time per shift}} \quad (10)$$

## Press Details

In this present study, data are obtained from a commercial newspaper printing house situated in Kolkata, India, during August-October, 2018.

The newspaper house consists of different types of machines with its supporting equipment out of which four equipments are selected on the basis of age, criticality factor and high-risk scenario for this pilot study.

These machines are: one Web-offset printing machine, two Computer-to-Plate (CTP) machines, one exposure unit. The web-offset printing machine [Make: The Printer's House, India; Model: Orient Xcell (3c-1)] of the press is basically a four colour web-machine installed in the year 2009 which is used for printing newspaper, book, magazine etc.

This indicates that the web-offset machine under the study can only handle the paper substrates and for this normal web-offset inks and consumables are used. Its daily capacity is 40000 to 41200 pieces of newspaper per hour. Press is using two Epson Sure-Colour T5270 (Ultra Colour XD ink) CTP machines which is installed at 2009 and 2014 for image printing on Aluminium or polyester plate.

Once the plate is imaged, it is exposed by the ultra-violet ray in Technova Proteck Ecolux-i, Exposure machine, installed at 2005.

Press is using Corrective or Breakdown method for the maintenance of the machines and this motivates towards further investigation on strategic planning for improvement of productivity and effectiveness. During this study, the average temperature inside the press was 27 – 33°C and average relative air humidity was 75 – 85%.

Moreover, as the printing job is mostly associated with newsprint thus the press uses the paper of the same grammage and printing is done mainly in night shift though 30% of the printing was done in both day and night shifts. Furthermore, it is assumed that the operational conditions are the same for all the machines.

## Proposed Frame-work

In the workflow of every commercial printing house, all the printing jobs are handled on high priority basis. Generally printing equipment works for both single, double or triple shifts a day based on the job pressure in the organization. The demand of jobs is directly related to production capacity and job handling approach.

But it is also necessary to monitor the machine's health, production rate, breakdown, root-causes of faults and maintenance procedure in terms of both time and cost to make proper performance planning.

The present study involves the identification and documentation of all parameter leading to the estimation of overall equipment effectivity metrics and productivity.

Moreover, this work is focused to examine the correlation among the potential parameters like OEE, Utilization Factor along with different kind of productivity metrics to fix a scale of reference for maintenance planning.

Finally, comparative analysis between all the factors is done on the ground of failure analysis, productivity analysis and effectiveness of equipment to establish the suitable maintenance technique. The flowchart given in Figure 1 represents the proposed framework of the methodology.

# Results

## Productivity

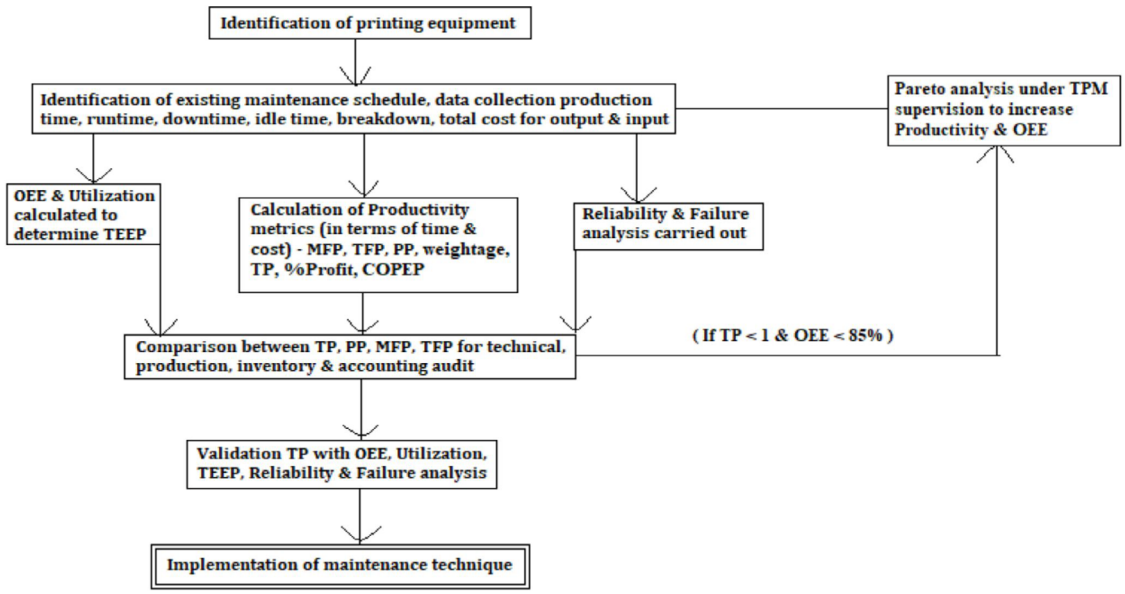
Productivity estimation is the most important part of a printing press for performance and apparent profit analysis. In this study, four equipments (namely web-offset printing machine, CTP1, CTP2 and exposure unit) are chosen in a conventional commercial printing press. Therefore, production audit is necessary to carry out different productivity metrics. If there is any kind of major breakdown during operation of vital machines and its supporting sub-components then it may arise huge loss which may reflect yearly financial turnover and upcoming budget planning. Therefore, it will also affect the future expansion of the press including expansion of company's client and staffs.

Basic data are collected from the commercial press includes runtime, planned production time and idle time in hours of each equipment for consecutive thirteen weeks. These representative data of different types of production time of web-offset printing machine and other prepress equipments are given in Table 1. These data are used to estimate productivity with respect to time, uptime and utilization by using Equations 1, 2 & 10.

Different input cost for different types of machines are collected from the press and given in the Table 2 to Table 5. The input costs of different machines include material cost, cost of energy consumption, maintenance cost and human wages. Here cost of spare parts and cost of repairing has been considered as maintenance cost. Multi-factor productivity (MFP) and profit percentage of different machines has been calculated for different weeks by using Equation 4 and Equation 8 respectively. Moreover, partial productivity (PP) and weightage factor of different machines have estimated by Equations 6 & 7 respectively by considering different input cost separately. Finally, total productivity, profit percentage, total factor productivity and multifactor productivity are calculated by using Equations 5, 8, 3 & 4 respectively which are based on total output and input costs for thirteen weeks.

## Combined Overall Press Productivity

Table 6 shows the values of Total Productivity (TP) in terms of cost, %Profit, TFP, MFP of four machines for convenience which clearly indicates the scenario of performance of these machines. From these parameters combined overall press equipment productivity (COPEP) is estimated with the help of Equation 9 and found to 1.5271. Considering the fact that profit will be zero for 100% productivity, overall profit percentage is found to be 52.71 (calculated from Equation 8). This indicates that the press is running with profit margin in-spite of loss for one machine.




» **Figure 1:** *Framework for proposed methodology*

**Table 1**

Time Productivity for printing machine and prepress equipments

| Parameter | Web-offset printing machine | CTP1 | CTP2 | Exposure Unit |
|---|---|---|---|---|
| Max available time (Hour) | 1391.5 | 1046.5 | 1046.5 | 1046.5 |
| Potential production time (Hour) | 362.8333333 | 117.0667 | 61.18333 | 152.9 |
| Actual production time (Hour) | 246.8833333 | 39.9 | 30.75 | 39.11666667 |
| Idle time (Hour) | 1028.666667 | 929.4333 | 985.3167 | 893.6 |
| Uptime | 0.9167 | 0.9263 | 0.9709 | 0.8913 |
| Productivity(in terms of time) | 0.6804 | 0.3408 | 0.5026 | 0.2558 |
| Utilization | 0.2607 | 0.1118 | 0.0584 | 0.1461 |

**Table 2 (part 1)**

Productivity in terms of cost for web-offset printing machine

| Week | Output Cost (Euro) | Material cost input (Euro) | Energy cost (Euro) | Maintenance cost (Euro) | Human weekly wages (Euro) | Multi-factor-productivity (MFP) | %Profit |
|---|---|---|---|---|---|---|---|
| wk1 | 32912.726 | 11927.192 | 340.878 | 10.067 | 433.701 | 2.589 | 158.91% |
| wk2 | 38486.035 | 13928.010 | 399.053 | 14.284 | 433.701 | 2.605 | 160.48% |
| wk3 | 27628.323 | 9974.330 | 323.810 | 16.263 | 433.701 | 2.571 | 157.05% |
| wk4 | 27077.646 | 9832.398 | 305.540 | 10.756 | 433.701 | 2.559 | 155.87% |
| wk5 | 29726.57 | 10839.123 | 375.735 | 567.000 | 433.701 | 2.434 | 143.35% |
| wk6 | 30139.763 | 10875.937 | 332.705 | 11.960 | 433.701 | 2.586 | 158.61% |
| wk7 | 43105.14 | 15642.030 | 487.518 | 20.221 | 433.701 | 2.599 | 159.93% |
| wk8 | 49850.435 | 18063.591 | 585.839 | 23.146 | 433.701 | 2.609 | 160.91% |
| wk9 | 45297.996 | 16373.504 | 509.153 | 25.900 | 433.701 | 2.612 | 161.20% |
| wk10 | 77917.788 | 28139.771 | 798.106 | 28.912 | 433.701 | 2.650 | 165.02% |
| wk11 | 35708.364 | 12930.826 | 355.782 | 6.367 | 433.701 | 2.601 | 160.14% |
| wk12 | 16501.84 | 5979.922 | 172.122 | 6.367 | 433.701 | 2.503 | 150.33% |
| wk13 | 22509.966 | 8192.601 | 247.124 | 5.507 | 433.701 | 2.535 | 153.52% |

**Table 2 (part 2)**

Productivity in terms of cost for web-offset printing machine

| | Cost (Euro) | Partial Productivity | Weightage |
|---|---|---|---|
| Total output cost (Euro) for 13 weeks | 476862.5923 | - | - |
| Material cost input (Euro) for 13 weeks | 172699.2338 | 2.7612 | 0.56029 |
| Total energy cost (Euro) for 13 weeks | 5233.36549 | 91.1197 | 0.01698 |
| Total maintenance cost (Euro) for 13 weeks | 746.751193 | 638.5830 | 0.00242 |
| Total human wages (Euro) for 13 weeks | 5638.117141 | 84.5783 | 0.01829 |
| Capital cost (Euro) for 13 weeks | 123914.6625 | 3.8483 | 0.40202 |
| SUM of all input (Euro) | 308232.13 | - | - |
| Total Productivity (TP) | → 1.547089177 | %Profit | → 54.7089% |
| Net output (Euro) | 292545.1247 | Total factor input (Euro) | → 129552.78 |
| Multi-factor-productivity (MFP) based on total cost for 13 weeks | → 2.587180686 | Total factor productivity (TFP) | → 2.25811538 |

**Table 3 (part 1)**

Productivity in terms of cost for CTP1

| Week | Output Cost (Euro) | Material cost input (Euro) | Energy cost (Euro) | Maintenance cost (Euro) | Human weekly wages (Euro) | Multi-factor-productivity (MFP) | %Profit |
|---|---|---|---|---|---|---|---|
| wk1 | 657.987 | 109.664 | 8.823 | 3.075 | 57.827 | 3.668 | 266.79% |
| wk2 | 747.205 | 124.534 | 9.437 | 3.121 | 57.827 | 3.833 | 283.34% |
| wk3 | 680.291 | 113.382 | 12.827 | 5.324 | 57.827 | 3.593 | 259.26% |
| wk4 | 568.768 | 94.795 | 10.290 | 322.843 | 57.827 | 1.171 | 17.09% |
| wk5 | 646.835 | 107.806 | 8.049 | 2.662 | 57.827 | 3.668 | 266.80% |
| wk6 | 613.378 | 102.230 | 10.270 | 4.050 | 57.827 | 3.518 | 251.75% |
| wk7 | 769.510 | 128.252 | 9.199 | 2.949 | 57.827 | 3.882 | 288.20% |
| wk8 | 914.490 | 152.415 | 14.929 | 5.806 | 57.827 | 3.959 | 295.92% |
| wk9 | 758.358 | 126.393 | 12.550 | 4.922 | 57.827 | 3.760 | 276.00% |
| wk10 | 814.119 | 135.687 | 10.349 | 3.465 | 57.827 | 3.927 | 292.67% |
| wk11 | 702.596 | 117.099 | 12.570 | 5.106 | 57.827 | 3.648 | 264.79% |
| wk12 | 368.027 | 61.338 | 8.188 | 3.603 | 57.827 | 2.810 | 181.03% |
| wk13 | 602.225 | 100.371 | 11.777 | 4.957 | 57.827 | 3.443 | 244.26% |

**Table 3 (part 2)**

Productivity in terms of cost for CTP1

| | Cost (Euro) | Partial Productivity | Weightage |
|---|---|---|---|
| Total output cost (Euro) for 13 weeks | 8843.78946 | - | - |
| Material cost input (Euro) for 13 weeks | 1473.96491 | 6.0000 | 0.19159 |
| Total energy cost (Euro) for 13 weeks | 139.256773 | 63.5071 | 0.01810 |
| Total maintenance cost (Euro) for 13 weeks | 371.880986 | 23.7812 | 0.04834 |
| Total human wages (Euro) for 13 weeks | 751.748952 | 11.7643 | 0.09771 |
| Capital cost (Euro) for 13 weeks | 4956.5865 | 1.7843 | 0.64426 |
| SUM of all input (Euro) | 7693.43812 | - | - |
| Total Productivity (TP) | → 1.1495237 | %Profit | → 14.9524% |
| Net output (Euro) | 6106.93784 | Total factor input (Euro) | → 5708.33545 |
| Multi-factor-productivity (MFP) based on total cost for 13 weeks | → 3.23137337 | Total factor productivity (TFP) | → 1.06982813 |

**Table 4 (part 1)**

Productivity in terms of cost for CTP2

| Week | Output Cost (Euro) | Material cost input (Euro) | Energy cost (Euro) | Maintenance cost (Euro) | Human weekly wages (Euro) | Multi-factor-productivity (MFP) | %Profit |
|---|---|---|---|---|---|---|---|
| wk1 | 278.808 | 46.468 | 4.818 | 1.354 | 57.827 | 2.524 | 152.39% |
| wk2 | 223.046 | 37.174 | 4.322 | 1.067 | 57.827 | 2.222 | 122.18% |
| wk3 | 278.808 | 46.468 | 5.095 | 1.515 | 57.827 | 2.514 | 151.39% |
| wk4 | 412.636 | 68.773 | 6.721 | 1.767 | 57.827 | 3.055 | 205.46% |
| wk5 | 289.960 | 48.327 | 8.208 | 329.213 | 57.827 | 0.654 | -34.63% |
| wk6 | 345.722 | 57.620 | 5.730 | 1.595 | 57.827 | 2.816 | 181.60% |
| wk7 | 345.722 | 57.620 | 6.146 | 1.778 | 57.827 | 2.802 | 180.23% |
| wk8 | 457.245 | 76.208 | 8.129 | 2.352 | 57.827 | 3.164 | 216.40% |
| wk9 | 334.570 | 55.762 | 6.047 | 1.778 | 57.827 | 2.756 | 175.56% |
| wk10 | 345.722 | 57.620 | 5.531 | 1.423 | 57.827 | 2.824 | 182.45% |
| wk11 | 323.417 | 53.903 | 5.749 | 1.664 | 57.827 | 2.715 | 171.45% |
| wk12 | 156.132 | 26.022 | 2.736 | 0.780 | 57.827 | 1.787 | 78.71% |
| wk13 | 256.503 | 42.751 | 3.945 | 0.964 | 57.827 | 2.432 | 143.16% |

**Table 4 (part 2)**

Productivity in terms of cost for CTP2

| | Cost (Euro) | Partial Productivity | Weightage |
|---|---|---|---|
| Total output cost (Euro) for 13 weeks | 4048.29202 | - | - |
| Material cost input (Euro) for 13 weeks | 674.715337 | 6.0009 | 0.18208 |
| Total energy cost (Euro) for 13 weeks | 73.1772135 | 55.3299 | 0.01975 |
| Total maintenance cost (Euro) for 13 weeks | 347.249364 | 11.6599 | 0.09371 |
| Total human wages (Euro) for 13 weeks | 751.748952 | 5.3860 | 0.20287 |
| Capital cost (Euro) for 13 weeks | 1858.71993 | 2.1783 | 0.50160 |
| SUM of all input (Euro) | 3705.61080 | - | - |
| Total Productivity (TP) | → 1.09247631 | %Profit | → 9.2476% |
| Net output (Euro) | 2201.40115 | Total factor input (Euro) | → 2610.468889 |
| Multi-factor-productivity (MFP) based on total cost for 13 weeks | → 2.19194977 | Total factor productivity (TFP) | → 0.843297219 |

**Table 5 (part 1)**

Productivity in terms of cost for exposure unit

| Week | Output Cost (Euro) | Material cost input (Euro) | Energy cost (Euro) | Maintenance cost (Euro) | Human weekly wages (Euro) | Multi-factor-productivity (MFP) | %Profit |
|---|---|---|---|---|---|---|---|
| wk1 | 187.359 | 14.870 | 6.580 | 2.907 | 40.479 | 2.890 | 188.97% |
| wk2 | 191.820 | 16.728 | 9.071 | 4.482 | 40.479 | 2.711 | 171.09% |
| wk3 | 189.589 | 14.870 | 7.311 | 3.373 | 40.479 | 2.871 | 187.11% |
| wk4 | 191.820 | 16.728 | 7.807 | 3.662 | 40.479 | 2.793 | 179.31% |
| wk5 | 187.359 | 16.109 | 7.051 | 3.213 | 40.479 | 2.803 | 180.26% |
| wk6 | 189.589 | 16.728 | 8.699 | 4.241 | 40.479 | 2.703 | 170.28% |
| wk7 | 220.816 | 19.207 | 8.538 | 3.919 | 40.479 | 3.061 | 206.08% |
| wk8 | 269.886 | 22.924 | 11.425 | 5.413 | 40.479 | 3.363 | 236.34% |
| wk9 | 218.585 | 19.207 | 9.727 | 4.690 | 40.479 | 2.950 | 194.97% |
| wk10 | 252.042 | 21.685 | 10.211 | 4.803 | 40.479 | 3.266 | 226.58% |
| wk11 | 205.203 | 17.968 | 11.115 | 5.670 | 40.479 | 2.728 | 172.76% |
| wk12 | 104.832 | 12.391 | 6.741 | 3.614 | 40.479 | 1.658 | 65.81% |
| wk13 | 171.746 | 13.631 | 9.405 | 4.843 | 40.479 | 2.512 | 151.25% |

**Table 5 (part 2)**

Productivity in terms of cost for exposure unit

| | Cost (Euro) | Partial Productivity | Weightage |
|---|---|---|---|
| Total output cost (Euro) for 13 weeks | 2580.64676 | - | - |
| Material cost input (Euro) for 13 weeks | 223.046392 | 11.5700 | 0.08033 |
| Total energy cost (Euro) for 13 weeks | 113.678856 | 22.7012 | 0.04094 |
| Total maintenance cost (Euro) for 13 weeks | 54.8304014 | 47.0660 | 0.01975 |
| Total human wages (Euro) for 13 weeks | 526.224266 | 4.9041 | 0.18953 |
| Capital cost (Euro) for 13 weeks | 1858.71993 | 1.3884 | 0.66945 |
| SUM of all input (Euro) | 2776.49985 | - | - |
| Total Productivity (TP) | → 0.92946043 | %Profit | → -7.0540% |
| Net output (Euro) | 1662.86684 | Total factor input (Euro) | → 2384.944203 |
| Multi-factor-productivity (MFP) based on total cost for 13 weeks | → 2.81183616 | Total factor productivity (TFP) | → 0.697235114 |

**Table 6**

Performances of machines under study

| | Web-offset printing machine | CTP1 | CTP2 | Exposure Unit |
|---|---|---|---|---|
| Total Productivity (TP) | 1.5471 | 1.1495 | 1.0925 | 0.9295 |
| %Profit | 54.71 | 14.95 | 9.25 | -7.054 |
| Total-factor productivity (TFP) | 2.2581 | 1.0698 | 0.8433 | 0.6972 |
| Multi-factor-productivity (MFP) | 2.5872 | 3.2314 | 2.1919 | 2.8118 |

# Analysis

Variation of multifactor productivity of all the machines in terms of soft factor (like material, labor, energy, maintenance and other expenses etc.) with number of weeks are shown in Figure 2 and analyzed to understand the profit scenario against weekly variable inputs and to evaluate the material consumption, machine performance and human effort. Figure 3 demonstrates the comparative analysis of total productivity (TP), profit percentage, total factor productivity (TFP), multi factor productivity (MFP) of all the machines under study.

Here TFP value (2.2581, 1.0698, 0.8433 & 0.6972) is estimated for easy sales analysis purpose, MFP value (2.5872, 3.2314, 2.1919 & 2.8118) is calculated for daily basis performance and inventory audit and TP is estimated for actual production audit. This shows that web-offset machine has highest value of TP of 1.5471 resulting highest percentage profit of 54.709% whereas exposure unit shows the lowest TP of 0.9295 having lowest percentage profit of-7.054%. Now, COPEP metrics is giving an overall productivity value 1.5271 and the overall profit of press of 52.71% which may help for further effective management of press for improved productivity. It is also observed that the COPEP value is nearest to the TP value of web-offset printing machine and this is because the output and input value of other machines are also component and sub-component of main web-offset printing machine.

## Validation of Productivity with Effectivity

Different performance parameters of the machines of the newspaper printing press are illustrated in Table 7 for comparative analysis. To validate the values of TP of four equipments, overall equipment efficiency (OEE) values of machines are determined by using Equation 10.

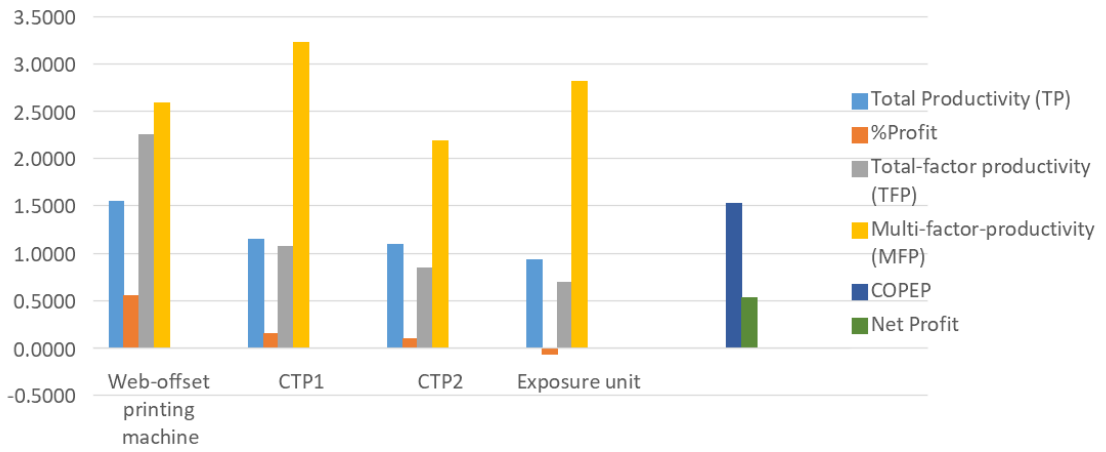
Also, total effective equipment performance (TEEP) and utilization factor of all the equipment have been estimated. It is seen that web-offset printing machine possess highest TP value, OEE, Utilization factor, TEEP metric.

The TEEP value is demonstrating the actual performance value of all the machines on the basis of maximum utilized time for production and actual equipment effectivity status. It is previously seen by the authors (Kar & Pal, 2022) that the Failure Probability and corresponding Reliability of web-offset printing machine and associated prepress equipments can be estimated by using the method of Risk Based Maintenance (RBM) strategy.

The values of failure probability and reliability of all the machines are demonstrated also in Table 7.

Figure 4 shows the corresponding bar chart to compare the values of TP, OEE, Utilization and TEEP with failure probability and reliability of the machines.


» **Figure 2:** *Weekly variation of Multi-factor Productivity (MFP):*
*(a) Web-offset printing machine,*
*(b) CTP1,*
*(c) CTP2, and*
*(d) Exposure unit*




» **Figure 3:** *Overview of productivity metrics of press*

From this it is very much clear that exposure unit has lowest productivity of 0.9295 value, lowest OEE of 0.252235 value & lowest reliability of 0.19399 and highest failure probability of 0.80601. From the productivity analysis, it indicates that exposure unit has lowest production rate. OEE metrics is categorizing the effectivity of the machine in descending order for further corrective and preventive maintenance planning for the improvement of CTP sections. Utilization factor is helping for the job scheduling and capacity planning of all the press equipment. Reliability and failure analysis is demonstrating the knowledge of machine health & life cycle and vast knowledge of failure occurrence to the management for further strategic and breakdown maintenance. TEEP value is indicating for the predictive maintenance of CTP2 as it has lowest value of 0.0231 for further improvement of its performance.

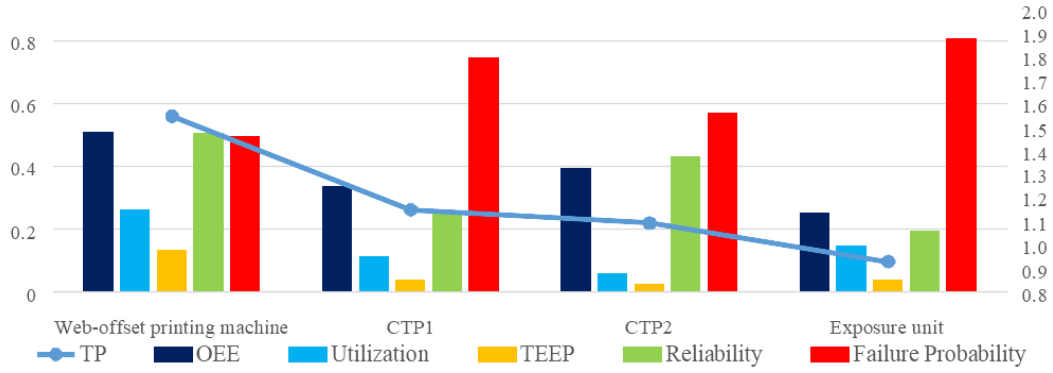
## Pareto Analysis

It is pertinent to mention that exposure unit is having the highest failure rate whereas web-offset printing machine posses lowest failure rate which indicates total productivity of exposure unit is very less compared to the web-offset machine. In order to develop further maintenance planning for improved productivity, root-cause of failures of the machines should be analyzed. For this Pareto charts for individual machine can be generated by using statistical software Minitab17. Figure 5 illustrates Pareto analysis for web-offset printing machine which is based on different causes of breakdown and failures. It is observed that loading-unloading of paper reel into web-offset printing machine causes maximum downtime. Similar chart can be easily generated from other machines to identify the causes of failure.

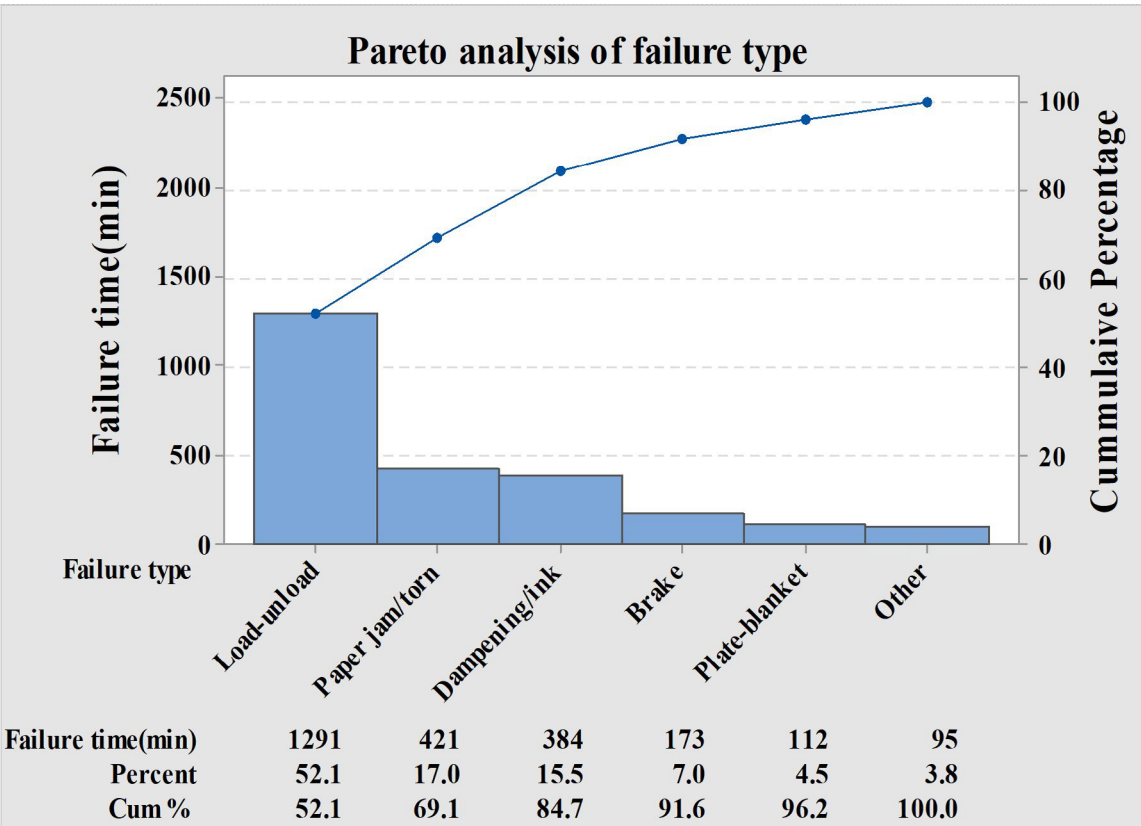
**Table 7**

Comparative analysis of different effectivity metrics with TP

| Comparison of different effectivity metrics | | | | |
|---|---|---|---|---|
| | **Web-offset printing machine** | **CTP1** | **CTP2** | **Exposure unit** |
| TP | 1.5471 | 1.1495 | 1.0925 | 0.9295 |
| OEE | 0.5082 | 0.3350 | 0.3944 | 0.2522 |
| Utilization | 0.2607 | 0.1118 | 0.0584 | 0.1461 |
| TEEP | 0.1325 | 0.0375 | 0.0231 | 0.0369 |
| Failure Probability | 0.4955 | 0.7455 | 0.5685 | 0.8060 |
| Reliability | 0.5045 | 0.2545 | 0.4315 | 0.1940 |




» **Figure 4:** *Comparative analysis of different effectivity metrics with TP*




» **Figure 5:** *Pareto chart for Web-offset Printing Machine*

## Planning for Productivity Improvement

In order to increase the total productivity and overall effectiveness of the equipment, it is necessary to reduce the failure probability of the machines. And for this, further maintenance planning should be implemented. This will help to decrease the number of the failure which in-turn will support the effective productivity management. Table 8 represents the modified productivity (TP, TFP and MFP) along with OEE and utilization factor of all the machines after implementing further maintenance planning. This table also shows the results of failure reduction of all the machines.

The modified probability of failure has been determined by considering the fact that breakdown time or downtime can be reduced by decreasing the number of failures with the help of modern technology and management system. The modified values of effectiveness and utilization factors of all the machines indicate that the modified total productivity of all the machines increases with the increase of effectiveness (modified) of the corresponding machines.

Moreover, the decreased failure probability after modification has shown a strong effect on the improvement of total productivity. So, it can be postulated that the productivity of the machines of the newspaper printing press can be subsequently increased by applying this methodology which may be useful for the improvement of overall performance of the machines in a printing press.

## Conclusion

The proposed technique for productivity and effectiveness analysis predicts the failure frequency and risk pattern of all the equipment in the press. This prediction is used to evaluate the suitable interval of preventive maintenance program based on reducing the failures of the machines.

This methodology confirms that productivity of equipment can be enhanced by implementing further maintenance planning. This will contribute to the effective management of maintenance of printing machines to provide its optimal performance.

The present investigation also helps to identify the high risked machine in a newspaper printing press which involves the need for robust data collection and if the duration of data collection is extended then more accurate result can be achieved. It is concluded that the top management of a printing house has a scope of mechanism to adjust the failure probability of the machines after analyzing the number of failures as a function of interval period between preventive maintenance.

**Table 8**

Prediction of modified Productivity, OEE and Utilizations of the machines

| Resource | Modified | | | | Existing | | | |
|---|---|---|---|---|---|---|---|---|
| | Web-offset printing machine | CTP1 | CTP2 | Exposure unit | Web-offset printing machine | CTP1 | CTP2 | Exposure unit |
| Output Cost (Euro) | 474980.51 | 8709.96 | 4037.14 | 2580.65 | 476862.59 | 8843.79 | 4048.29 | 2580.65 |
| Material cost input (Euro) | 172141.13 | 1451.66 | 672.86 | 223.05 | 172699.23 | 1473.96 | 674.72 | 223.05 |
| Energy cost (Euro) | 4638.15 | 47.46 | 36.58 | 29.08 | 5233.37 | 139.26 | 73.18 | 113.68 |
| Maintenance loss cost (Euro) | 0.00 | 0.00 | 0.00 | 0.00 | 746.75 | 371.88 | 347.25 | 54.83 |
| Human weekly wages (Euro) | 5638.12 | 751.75 | 751.75 | 526.22 | 5638.12 | 751.75 | 751.75 | 526.22 |
| Capital cost (Euro) | 123914.66 | 4956.59 | 1858.72 | 1858.72 | 123914.66 | 4956.59 | 1858.72 | 1858.72 |
| SUM of all input (Euro) | 306332.06 | 7207.46 | 3319.90 | 2637.07 | 308232.13 | 7693.44 | 3705.61 | 2776.50 |
| Total Productivity (TP) | 1.5505 | 1.2085 | 1.2160 | 0.9786 | 1.5471 | 1.1495 | 1.0925 | 0.9295 |
| % Profit | 0.5505 | 0.2085 | 0.2160 | -0.0214 | 0.5471 | 0.1495 | 0.0925 | -0.0705 |
| Net output (Euro) | 292563.11 | 6459.09 | 2575.96 | 1802.29 | 292545.12 | 6106.94 | 2201.40 | 1662.87 |
| Total factor input (Euro) | 129552.78 | 5708.34 | 2610.47 | 2384.94 | 129552.78 | 5708.34 | 2610.47 | 2384.94 |
| Total factor productivity (TFP) | 2.2583 | 1.1315 | 0.9868 | 0.7557 | 2.2581 | 1.0698 | 0.8433 | 0.6972 |
| Multi-factor-productivity (MFP) without capital | 2.6038 | 3.8696 | 2.7629 | 3.3155 | 2.5872 | 3.2314 | 2.1919 | 2.8118 |
| Productivity (in terms of time) | 0.7196 | 0.7191 | 0.8099 | 0.2620 | 0.6804 | 0.3408 | 0.5026 | 0.2558 |
| OEE | 0.5374 | 0.7038 | 0.6356 | 0.2583 | 0.5082 | 0.3350 | 0.3944 | 0.2522 |
| Utilization | 0.2466 | 0.0530 | 0.0363 | 0.1427 | 0.2607 | 0.1119 | 0.0585 | 0.1461 |
| TEEP | 0.1325 | 0.0373 | 0.0231 | 0.0369 | 0.1325 | 0.0375 | 0.0231 | 0.0369 |
| Failure probability | 0.4741 | 0.6535 | 0.5025 | 0.7995 | 0.4955 | 0.7455 | 0.5685 | 0.8060 |

Moreover, the proposed methodology seems to be novel as it supports not only Productivity Management but also Maintenance Management due to quantitative estimation of failure probability and associated costs of the machines. Finally, it is suggested that this approach may support top management in complying with the requirement of quality print production for enhanced productivity of the equipment.

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