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An Implementation of ANOVA and Six-Sigma for Productivity Improvement in Printing Machines

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Abstract
Increasing productivity is currently the biggest challenge for manufacturing industries in terms of implementation of Industry 4.0 technologies. This article deals with the widely used methods of measuring of overall equipment effectiveness that in combination with statistical approaches confirms the growth in productivity and seems to be simple and novel technique particularly in the field of printing industries. The aim of the present study is to determine quantitatively the productivity, effectiveness, utilization, risk factor and sigma level of some machines in a printing company that are validated by the selected statistical approaches such as six sigma and analysis of variance techniques. Machine operating time, machine downtime and machine idle-time of different machines in a printing house are considered as main variable parameters for analysis of variance and six-sigma analysis. The results show that the proposed methodology can be a promising development towards improvement of productivity parameters of machines in the printing house.

Keywords
Machine Operating time, Machine Downtime, Machine Idle-time, ANOVA, Statistical Process Control.

Introduction

Productivity improvement nowadays plays a very important role in every manufacturing industry including printing. Machine productivity is a simple calculation consisting of the total volume produced divided by the number of machines used. Effective management of maintenance of the machines in a printing company is a common problem. If proper maintenance strategy is applied, productivity of printing machines can be increased by reducing breakdown and number of failures. The present investigation is established by the analysis of productivity, effectiveness, utilization, failure probability, risk factor and sigma level on the basis of risk-based maintenance (RBM) strategy. The downtime associated with breakdown, idle time, make-ready time, loss of production etc. are main concerns in a print production house.

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Based on the existing problem of machines in a printing house, a proposed methodology has been suggested by conducting an in-depth statistical analysis of variance (ANOVA) test to find out the significant influencing parameters acting as obstruction towards high production system. With a controlled system such as lean six sigma (LSS), production status for the variation of process performance, different parameters related with the production output are monitored by using different statistical process control (SPC) charts. It will help the manufacturing sector to understand the total maintenance status and cost of production along with different input parameters. It will also help the management to understand the proper yearly budget as well as primary key factors to counter the negative catalysts of production in the system.

The results obtained show that the proposed methodology works accurately for improvement of productivity parameters, which is the need for the effective maintenance management of a production house. This type of approach for improving productivity of the machines along with its validation technique by using ANOVA and six-sigma methods seems to be a new contribution for the continuous monitoring of productivity data of machines in a printing company, which may reflect the novelty of this research work.

Literature Review

Over the many year, various researchers and scientists are continuously working for the elimination of every minute faults or giant loop holes in techno-managerial systems to production machine systems to overcome the future consequences of risk so that the production system is not affected in their daily scheduled jobs.

Effectiveness measurement is a key performance indicator for every manufacturing industry by introducing Total Productive Maintenance (TPM) concept by which efficiency and performance of a system can be improved (Nakajima, 1998). Over time, many studies have been reviewed and developed by researchers for the statistical modelling, such as ANOVA (Fujikoshi, 1993); however, it was not so popular due to inefficient implementation in any industry.

After the development of total productive maintenance (TPM) methodology, it had been implemented in different manufacturing industries whose main purpose was to improve productivity in terms of overall equipment effectiveness (OEE). The measurement of OEE generally helps to monitor the present production status, which may further help for improved maintenance planning to increase the overall productivity. Moreover, the idea of lean manufacturing and six-sigma is successfully implemented to analyse the efficiency in a production enterprise (Hamrol & Bozek, 2012). Again in a printed circuit board manufacturing company, ANOVA is applied to find out the best fitted factors for better productivity (Ng et. al., 2014).

Control chart in terms of factor effect study can be used to conduct ANOVA study for controlling production process to understand whether the outliers point in control chart is significant or not (Ghosh et. al., 2019). The uncontrolled input can be summarized in box plot for further normal probability or histogram analysis of uncontrolled input samples. Then the residual analysis from ANOVA technique as a scientific indicator was used for process modelling of production machines such as lathe machines in a production company to control its quality (Hussain, 2019). Improvement of productivity measurement of an electrical conductor and efficiency of tools were compared by ANOVA, residual analysis and Tukey test to understand the unpredictable cum unstable behaviour of a system (Zamora-Antuñano et. al., 2019). To reduce the waste and cost of a production process, the single minute exchange of die technique was used as a lean manufacturing approach for the increment of OEE and machine availability by 3.26% and 4.86% in extrusion machines by targeting different time for setup, changeover, removal, maintenance etc. (Haddad et. al., 2021).

By implementing ANOVA in a textile manufacturing unit, it was found that machine productivity has a negative impact on the quality and its effectivity, weaving process and overall process was improved by 21%, 23% & 17.06% with proper managerial systematic techniques (Saad et. al., 2019).

Finally, it can be said that ANOVA can be utilized for the determination of the optimal parameters and the impact of the chosen parameters on the basis of performance is assessed (Eltaweel et. al., 2022) and it will optimize and predict the best fitted factor for example input volt, rotation angle, tilt angle, productivity etc. of a thermoelectric cooler-based dehumidification system. A very recent study of Lean Six Sigma with one-way ANOVA shows that the hypothesis testing was implemented in Vietnamese mechanical plant on a monthly basis to monitor the improvement of operation, good output, production time etc. and decrement of material cost, labour cost, tool cost, etc. (Duc & Thu, 2022). A qualitative technique of risk estimation by using a combined method of failure mode and effect analysis (FMEA) and technique for order of performance by similarity to ideal solution had been developed in a diary manufacturing company to control the productivity in terms of customer's satisfaction, sales and profit (Sharifi et. al., 2022). Recent trends are also motivating institutional managers to shift conventional production process to fast forwarding human-less production system with the OEE and the recent modern technology, such as simulation software, artificial intelligent, machine learning etc. for changing overall Industry 4.0 into Industry 5.0 (Pekarcikova et. al, 2023). Six-Sigma approach has also been used for the improvement of overall effectiveness of machines in palm oil industry of Indonesia (Nurprihatin et. al, 2023).

The significant related works carried out recently are shown in Table 1 representing a comparative overview of the approaches towards productivity improvement. Though these papers having more or less same objective, the present investigation focuses some research gap and bring a new perspective on how OEE and other productivity parameters, such as failure probability, reliability, and risk index, can be integrated with ANOVA and Statistical Process Control (SPC). As a result, efficient maintenance management can be implemented to provide optimal performance in a production house.

Table 1
Comparison of the present investigation with some recent works

Literature Review	Problem Addressed	Tools or Technique used	Benefits obtained
Haddad et. al., 2021	Reduction of waste and cost of production process	Lean manufacturing approach	Increment of overall effectiveness
Eltaweel et. al., 2022	Optimization of performance parameters of production system	ANOVA	Prediction of best fitted performance parameters
Duc & Thu, 2022	Monitoring of different production parameters	Lean Six-Sigma	Improvement of productivity of a mechanical plant
Sharifi et. al., 2022	Risk estimation of diary manufacturing unit	Failure mode and effect analysis (FMEA)	Control of productivity in terms of customers' satisfaction, sales and profit
Pekarcikova et. al, 2023	Testing the overall efficiency of equipment in a production process	Longest common subsequence (LCS) algorithm along with Cluster analysis	Measurement of overall effectiveness
Nurprihatin et. al., 2023	DMAIC approach to determine OEE	Six-Sigma technique	Minimization of product defect and machine downtime
This Paper	Increasing productivity, sigma level and decreasing risk factor	ANOVA and Six-Sigma	Improvement of total productivity, overall effectiveness, utilization factor, failure probability, reliability, risk index and sigma level.

In this study a new framework has been designed on the basis of machine operating time (MOT), machine downtime (MDT) and machine idle time (MIT) for ANOVA and SPC analysis. These analyses show the measurement and improvement of total productivity along with its effectiveness, utilization, failure probability and risk index (RI) of different machines in a printing company.

Methods

Lean Six Sigma

From the definition of Lean Six Sigma and DMAIC process (Define (D), Measure (M), Analyze (A), Improve (I) and Control (C)) it is seen that this methodology is highly structured and disciplined technique for monitoring the production workflow efficiently and minimization of maximum wastage of the company. Due to its interconnected properties the five logical steps are continuously working for the ongoing improvement of the project. Therefore, through the DMAIC process the whole production process can be controlled through wastage reduction by validating the improvement with project goals. Then final implementation of DMAIC phases can be applied after statistical hypothesis testing such as ANOVA and SPC, which in turn can set up a benchmark for process control of any production house or manufacturing unit

Statistical Process Control (SPC)

Statistical process control is used to check the stability of process by comparing common causes of variation from assignable causes of variation. If probability distribution of a statistical model is constant over time then the process is in stable or under statistically controlled. It is a basic chart of continuous individual data points with the central average line, upper and lower control limit (UCL & LCL) as shown in Equation 1 and 2. Now, the process is said to be in control if the data points fall within these control limits (UCL & LCL), otherwise the process is said to be out of control (Ghosh et. al., 2019). This method helps to support in making adjustment, improving and stabilizing the process with the help of modern technology and efficient maintenance management techniques.

$$\text{LCL for individual (I) chart} = \mu - k\sigma \tag{1}$$

$$\text{UCL for individual (I) chart} = \mu - k\sigma \tag{2}$$

where, 'μ' is the process mean for central line of individual values x (also known as '$\bar{x}$' for individual process control), 'σ' is the process standard deviation and 'k' is the parameter for individual process test and its default value is 3. Individual process control chart will help in detecting the relatively large shifts in the process average.

In this study, SPC tool is used to monitor the continuous assessment of production parameters such as wastage, downtime, quality, and availability within control limits (LCL & UCL) without compromising safety. It will give an overview regarding how to measure product performance so that it can be realized the scope of higher productivity, increased customer satisfaction, reduced scrap, better use of resources, reduced costs and warranty claims.

ANOVA

ANOVA is an analytical tool used in statistics that splits an observed aggregate variability found inside a dataset. It is used to test a hypothesis in which the null hypothesis (H_0) is accepted or rejected in relation to an alternative hypothesis (H_1) based on the statistic being lying in the acceptance region or the rejection region with certain level of probability of error being considered. The F-value in the ANOVA is calculated by dividing two mean squares, which determines the ratio of explained variances to unexplained variances. If the null hypothesis (H_0) is true, F-value must have a value close to one most of the time. However, if F-value is equal to or larger than critical F-value then the result will be significant at that level of probability and then null hypothesis (H_0) is rejected and alternate hypothesis (H_1) is accepted.

The F-value in ANOVA test also determines the p-value, this value is the probability of getting a result at least as extreme as the one that was actually observed. If the p-value is 0.05 or lower, the result will be significant but if it is higher than 0.05 then result is insignificant. Moreover, if the p-value is under 0.01, then results are considered statistically significant and if it is below 0.005 then they are considered highly statistically significant. In general, it can be said that smaller the p-value, the greater statistical incompatibility of the data with the null-hypothesis (H_0) (Ghosh et. al., 2019). Also on the basis of diverse set of observed data, two-way ANOVA techniques are chosen. Lastly this technique is used for better performance in each experiment to plan proper maintenance procedure.

Methodology

Press Details

The present study had been conducted on a Kolkata based printing company in India during the time period of August, 2018 to October, 2018. In the said company there were different types of printing machineries and supporting sub-equipment. Only four machines are chosen in this study on the basis of high failure rate and critical risk scenario. The four machines are respectively one web-offset printing machine (Orient Xcell(3c-1) manufactured in 2009 by TPH, India), two computer-to-plate machines (Sure-Colour T5270 (Ultra Colour XD ink) manufactured in 2009 & 2014 by Epson) and one exposure machine (Proteck, Ecolux-i manufactured in 2005 by Technova). Web-offset printing machine produces newspaper, printed sheet, book, magazine, catalogue, weekly supplements etc as an output. It can only handle newsprint or lower gsm paper substrate and only normal web-offset inks and other conventional consumables were used for its production with an average speed of 40000-41200 pieces of newspaper per hour. CTP machines are used to transfer the image of the digital data (printed matter) into the polyester plate. The image is then exposed by exposure unit under high intensity ultra-violet light source, which also helps to cure the emulsion surrounding the printed image. The average temperature inside the printing house was 27–33°C with general controlled humidity of 70-80%. Moreover, printing processes were conducted mainly in night shift though 30% of the printing job was noted both in day and night shifts. Furthermore, it is assumed that the operational conditions of all the machines under study remain same.

Proposed Framework

The proposed methodology has been demonstrated in the framework as shown in Figure 1. The current status of maintenance schedule, production output, MOT, MDT, MIT, different production costs and breakdown reasons etc. have been defined by collecting data from the printing house that have been used to measure the effectivity, total productivity (TP), reliability, availability, failure probability, consequences of failure, risk factor etc. as a part of DMAIC process. Also box-plots of downtime, runtime and failure number need to demonstrate for the visual representation of collected data of various machines in the printing house. It is also required to calculate the OEE, utilization factor (UF), capacity cushion (CC), total equipment effective performance (TEEP), reliability, risk index (RI) and sigma level for comparative analysis of present scenario.

ANOVA test has been conducted to find out the responsible significant factors of MOT, MDT and MIT of different machines. Residual analysis has also been performed to show the variation between observed value and estimated value. To understand the present scenario of production process and for further productivity improvement of the different machines of the printing house, the variation of process performance and production output are then analysed by applying Six Sigma and Statistical Process Control (SPC) method. Risk-based Maintenance (RBM) methodology developed earlier (Kar & Pal, 2019, Kar & Pal, 2022) has been used to analyse effectiveness, utilization, failure probability, risk factor and also productivity of different machines of the printing house for the further production improvement. The improved productivity and effectivity parameters of the machines are also validated and confirmed by the analysis of SPC. For SPC analysis the significant factors for MOT, MDT and MIT obtained from ANOVA test are used. The proposed methodology of implementation of statistical approach by using ANOVA and SPC for productivity improvement needs continuous monitoring by SPC tools and tracking OEE scores of the production process. This continuous monitoring and tracking for both pre and post recommended maintenance planning is essential for its productivity and effectivity improvement.

Results

On the basis of observed collected data of every selected machines machine operating time (MOT), machine downtime (MDT) and machine idle time (MIT) has been extracted weekly and represented from Table A.1 to Table A.4 as given in Annexure. Here different kinds of operating time (OT) are noticed and categorized by both different types of speed and various kinds of production output (PO) for all the machines. Also it is noticed and summarized that how variation of speed of web-offset printing machine influences the breakdown, which is also subdivided into different kinds of breakdown types, such as loading-unloading (LDUL), tear down of paper (TR), cleaning, setup & other downtime (CSOD), other technical machine breakdowns (OTMB), which includes shaft-gear problem, plate or blanket problem, fountain solution or ink solution problem, and other prepress delay, delay in exposing bulb, system software malfunction. Furthermore, for machines CTP1, CTP2 and exposure unit the causes of breakdown due to loading unloading (LDUL), system malfunction or breakdown or schedule maintenance (SMBSM), prepress delay (PPD) and exposing bulb lighting delay (EBLD) are taken into consideration for this study. Idle-times of all the selected machines are influenced by different levels of nonproductive types, such as scheduled & unscheduled stops, as well as categorized by manmade & machine-made activities. These collected data have been used for the measurement of the efficiency of machines and operators, which can influence the productivity of the printing house. Utilization factor (UF) is used to understand the maximum utilized production time within available time per day or week or month or year etc and capacity cushion (CC) is the available reserved production time after proper utilization of machineries. Therefore, UF is 100% from available time then machine capacity has been properly utilized on that instantaneous time period and CC is zero. Being an important parameter total productivity with respect to cost is used to measure the overall machine efficiency, system efficiency or plant performance. This includes total aggregate output factors to total aggregate input factors. Effectivity metrics is the product of machine availability, performance and quality also termed as overall equipment efficiency (OEE) with a world class value of 85%. On extension of this factor, total effective equipment performance (TEEP) is introduced by multiplying with utilization factor (UF), which again is concerned with the spontaneous production period of machine within available usable time period. Moreover, it is also important to note that from the reliability analysis failure probability should be tested and monitored regularly as it will lead to the future maintenance planning of a printing house or other industry. Risk factor can be evaluated by the product of failure probability and its consequence and then the risk index can be quantified by the ratio of present risk factor and acceptable risk criteria. From the observed data the utilization factor, productivity, overall equipment effectiveness, capacity cushion, total effective equipment performance, failure probability, risk index etc. of all the machines under study have been calculated by using the technique mentioned earlier (Kar & Pal, 2022, Kar & Pal, 2024). Table 2 represents the different parameters of productivity for total 91 days.

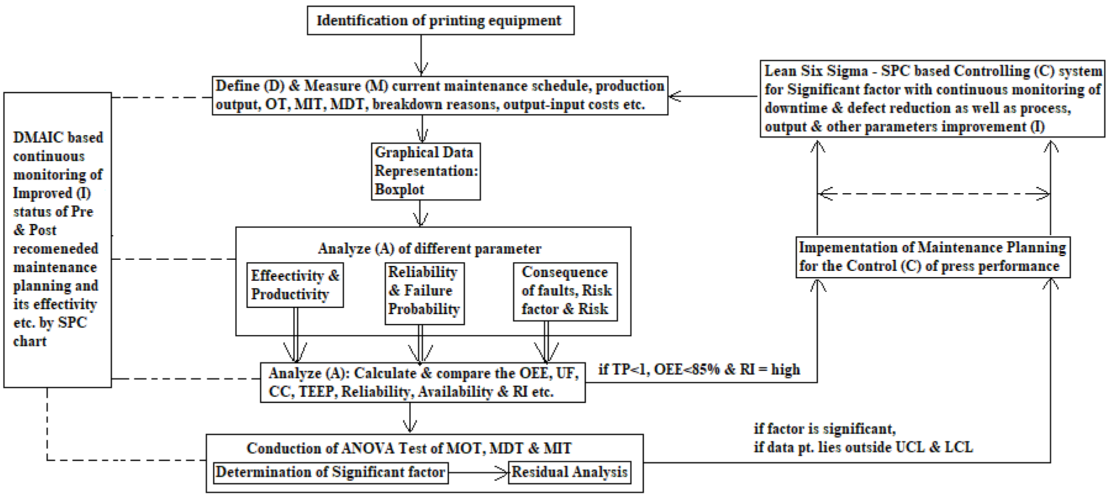

Fig. 1. Workflow of the proposed framework

Table 2
Productivity parameters of different printing equipment for total 91 days

Parameter	Web-offset printing machine	CTP1	CTP2	Exposure Unit
Max available time (hour)	1391.5000	1046.5000	1046.5000	1046.5000
Potential production time (hour)	362.8333	117.0667	61.1833	152.9000
Actual production time (hour)	246.8833	39.9000	30.7500	39.1167
Idle time (hour)	1028.6667	929.4333	985.3167	893.6000
Uptime (hour)	0.9167	0.9263	0.9709	0.8913
Productivity (in terms of time)	0.6804	0.3408	0.5026	0.2558
Total productivity (TP (in terms of Cost))	1.5471	1.1495	1.0925	0.9295
Utilization factor (UF)	0.2607	0.1119	0.0585	0.1461
Capacity cushion (CC)	0.7392	0.8881	0.9415	0.8538
Overall equipment effectiveness (OEE)	0.5082	0.3350	0.3944	0.2522
Total effective equipment performance (TEEP)	0.1313	0.0375	0.0231	0.0369
Failure Probability	0.4955	0.7455	0.5685	0.8060
Reliability	0.5045	0.2545	0.4314	0.1939
Risk index (RI)	1.6612	3.2912	2.1058	4.0621

Data Representation

The distribution of numerical data values has been represented by the box plot analysis for comparison of values between multiple graphs. Figure 2 shows the different kind of box-plot analysis of potential runtime, failure number and output status for all the four machines under study as an important step of DMAIC analysis for data collection. It is used to interpret in the form of graphical box-plot with mean, median, the maximum and minimum observation range, quartile range and outlier point of statistical dataset of each machine, which motivates us to initiate the use of different kinds of statistical tools to optimize the production process. Though it is demonstrating the comparisons of range and distribution for the large random dataset of a group in a well-mannered visual representation system with outlier values but it is not revealing the distribution pattern of the observed runtime, failure or output data as shown in Figure 2. However, the variable and continuous collected data of runtime, failure and output pattern is summarized and seen that mean, median and outlier values etc. are different for different machines. To allow the outlier values in box-plots, scales on the axes are set in different ranges. The collected data have different representation thus it is not holding any specific pattern of variation in production data, such as production output and potential operating time influencing breakdowns or idleness of the machines. So to understand that pattern it can be further analyzed by using a statistical method such as ANOVA with its residual pattern with probability technique, histogram distribution etc. to optimize the production.

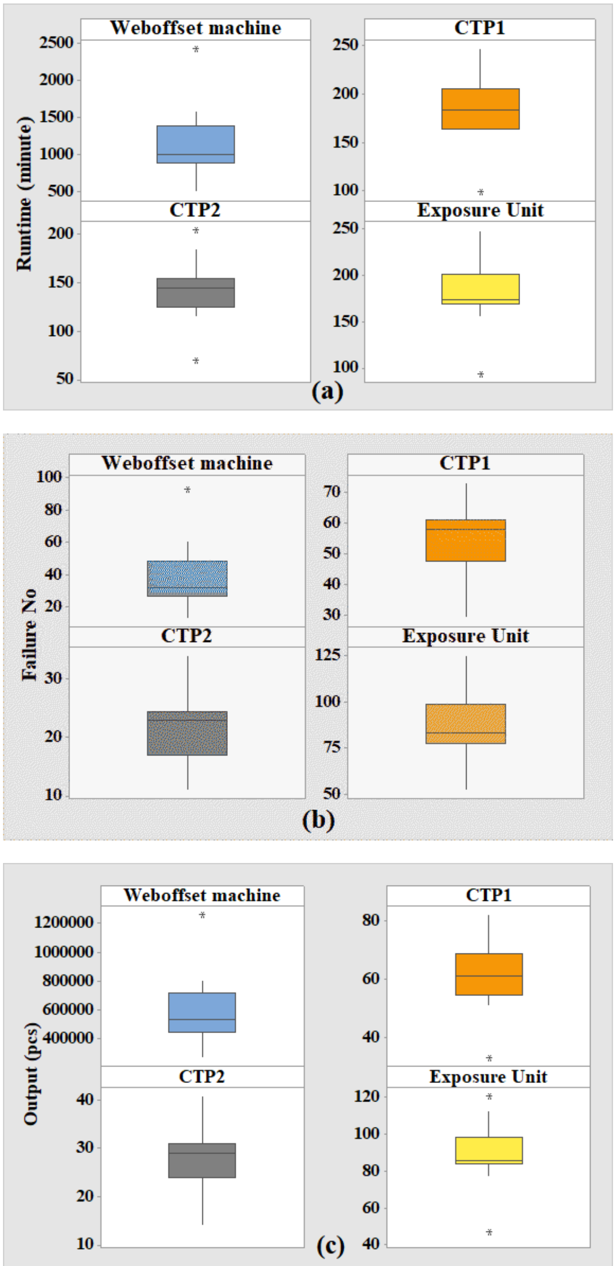

Fig. 2. Box-plot analysis of (a) Potential runtime, (b) Failure number & (c) Output of different machines

Analysis

It is important to note that productivity in terms of time ($|\mathrm{TP}|_{\mathrm{Time}}$) is the ratio of actual production time or runtime to potential time or planned production time whereas uptime is the ratio of summation of actual production and idle time to the total available production time.

It is seen that that from Table 2, only 26.07% is utilized by web-offset printing machine and it has productive time of only 68.04% that means only 246.88 hour is the output generating time out of total potential or planned production time of 362.83 hour. If the idle time of 1028.66 hour could have been used then it is seen that utilization rate, uptime rate and time-productivity rate will be better. It has been also observed that for exposure unit the actual production time is only 3.7372% of maximum available time and this indicates that if more jobs are carried out systematically then productivity could have been higher value than existing value of 0.2558. It is also observed that productivity in terms of cost is always higher than productivity with respect to time. And this is due to the reduced operational cost either by doing more work in less time or taking lesser hour to accomplish the work, which means that producing the same output requires less work force, which in turn increases profitability.

ANOVA Analysis

On the basis of collected raw data ANOVA analysis has been conducted to understand the exact status of production parameters. It will further help to choose the proper methodology for productivity improvement. ANOVA test of four machines under study have been conducted by considering the parameters, such as MOT, MDT and MIT of corresponding machines in the printing house. Here sum of squares (SS) has been partitioned by considering two-factorial design of machines under study, interaction between these two factors and their corresponding errors. The number of degrees of freedom (df) associated with each sum of squares (SS) is dependent on the corresponding levels of two factors and total number of replications. Mean squares (MS) are evaluated from each sum of squares divided by its degree of freedom. The total number of each parameters or variations for all the four machines and their corresponding schedules along with the levels of each factor for each variation are illustrated in Table 3.

Following null hypothesis (H_0) and alternative hypothesis (H_a) for different conditions, such as MOT, MDT and MIT of different machines are demonstrated below for better conduction of ANOVA test.

Table 3
Details of replications and levels of parameters for the machines under study

Name of machine	Parameters or Variation	Number of replications	Schedule of parameters or variations	Factors of each variation	Number of levels of each factor	Justification of level
Web-offset machine	MOT	26	OT for PO of good pieces for 13 weeks	PO	4	PO of good pieces of high OT
						PO of waste of high OT
						PO of good pieces of low OT
						PO of waste of low OT
			OT for PO of waste for 13 weeks	Speed	3	High
						Medium
						Low
	MDT	52	LDUL for 13 weeks	Breakdown type (BT)	4	BT due to LDUL
						BT due to TR
			TR for 13 weeks			BT due to OTMB
						BT due to CSOD
			OTMB for 13 weeks	Speed	3	High
						Medium
			CSOD for 13 weeks			Low
	MIT	52	Manmade schedule stop for 13 weeks	Non-productive type	2	Schedule stop
			Manmade un-schedule stop for 13 weeks			Un-schedule stop
			Machine-made schedule stop for 13 weeks	Man/machine made	2	Manmade stop
			Machine-made un-schedule stop for 13 weeks			Machine-made stop
CTP1	MOT	13	OT for high & low PO for 13 weeks	PO	2	OT for high PO
						OT for medium PO
				Speed	2	High
						Medium
	MDT	39	LDUL for 13 weeks	Breakdown type (BT)	3	BT due to LDUL
						BT due to SMBSM
			SMBSM for 13 weeks			BT due to PPD
				Speed	2	High
			PPD for 13 weeks			Medium
	MIT	52	Manmade schedule stop for 13 weeks	Non-productive type	2	Schedule stop
			Manmade un-schedule stop for 13 weeks			Un-schedule stop
			Machine-made schedule stop for 13 weeks	Man/machine made	2	Manmade stop
			Machine-made un-schedule stop for 13 weeks			Machine-made stop

Name of machine	Parameters or Variation	Number of replications	Schedule of parameters or variations	Factors of each variation	Number of levels of each factor	Justification of level
CTP2	MOT	13	OT for high & low PO for 13 weeks	PO	2	OT for high PO
						OT for medium PO
				Speed	2	High
						Medium
	MDT	39	LDUL for 13 weeks	Breakdown type (BT)	3	BT due to LDUL
						BT due to SMBSM
			SMBSM for 13 weeks			BT due to PPD
				Speed	2	High
			PPD for 13 weeks			Medium
	MIT	52	Manmade schedule stop for 13 weeks	Non-productive type	2	Schedule stop
			Manmade un-schedule stop for 13 weeks			Un-schedule stop
			Machine-made schedule stop for 13 weeks	Man/ machine made	2	Manmade stop
			Machine-made un-schedule stop for 13 weeks			Machine-made stop
Exposure unit	MOT	13	OT for high & low PO for 13 weeks	PO	2	OT for high PO
						OT for medium PO
				Speed	2	High
						Medium
	MDT	52	LDUL for 13 weeks	Breakdown type (BT)	4	BT for LDUL
						BT for SMBSM
			SMBSM for 13 weeks			BT for EBLD
						BT for PPD
			EBLD for 13 weeks	Speed	2	High
			PPD for 13 weeks			Medium
	MIT	52	Manmade schedule stop for 13 weeks	Non-productive type	2	Schedule stop
			Manmade un-schedule stop for 13 weeks			Un-schedule stop
			Machine-made schedule stop for 13 weeks	Man/ machine made	2	Manmade stop
			Machine-made un-schedule stop for 13 weeks			Machine-made stop

ANOVA test for MOT

H_0 : there is no significant effect on MOT for any PO factor for the machineries

H_a : there is significant effect on MOT for the PO factor for the machineries

H_0 : there is no significant effect on MOT for any speed factor for the machineries

H_a : there is significant effect on MOT for the speed factor for the machineries

H_0 : there is no significant interaction effect between speed & PO on MOT for the machineries

H_a : there is significant interaction effect between speed & PO on MOT for the machineries

ANOVA test for MDT

H_0 : there is no significant effect on MDT by speed factor for the machineries

H_a : there is significant effect on MDT by speed factor for the machineries

H_0 : there is no significant effect on MDT by breakdown type factor for the machineries

H_a : there is significant effect on MDT by breakdown type factor for the machineries

H_0 : there is no significant interaction effect between speed & breakdown type on MDT for the machineries

H_a : there is significant interaction effect between speed & breakdown type on MDT for the machineries

ANOVA test for MIT

H_0 : there is no significant effect on MIT for any man/machine made factor for the machineries

H_a : there is significant effect on MIT for the man/machine made factor for the machineries

H_0 : there is no significant effect on MIT for any nonproductive type factor for the machineries

H_a : there is significant effect on MIT for the non-productive type factor for the machineries

H_0 : there is no significant interaction effect between man/machine made & non-productive type on MIT for the machineries

H_a : there is significant interaction effect between man/machine made & non-productive type on MIT for the machineries

The results of the ANOVA tests for each machine are shown from Table 4 to Table 7 by considering MOT, MDT and MIT of the corresponding machines in the printing house as variable parameters and these have been obtained by using statistical software namely MINITAB17.

From these observations it can be said that more focus is needed to reduce the different elements of MIT for all the four machines under study. So it is needed to increase the utilization factor for improvement of MIT of machine. However, for exposure unit the MDT needs to be improved by reducing its variation factors.

The results of ANOVA tests for different machines motivate residual analysis of all the machines to show the variation between observed value and estimated value.

Residual Analysis

Residual value is the difference between the observed value and the estimated value and it will reveal whether the given dataset of MOT, MDT and MIT is appropriate for linear or nonlinear regression modeling. The scatter plot of residual values and fitted values (estimated response) are positioned in y-axis & x-axis respectively, which will detect the non-linearity, unequal error variances and outlier's points.

The residual patterns of individual machines of the printing house for its operational time, idleness causes and different types of breakdowns are able to identify various causes of obstruction for improved productivity and effectivity. From the collected dataset best fitted residual plot is represented in normal probability plot along with its fitted plot and histogram of collected data set of web-offset printing machine as shown in Figure 3. Thus, residual analysis is showing the probable modified pattern of MOT, MDT & MIT.

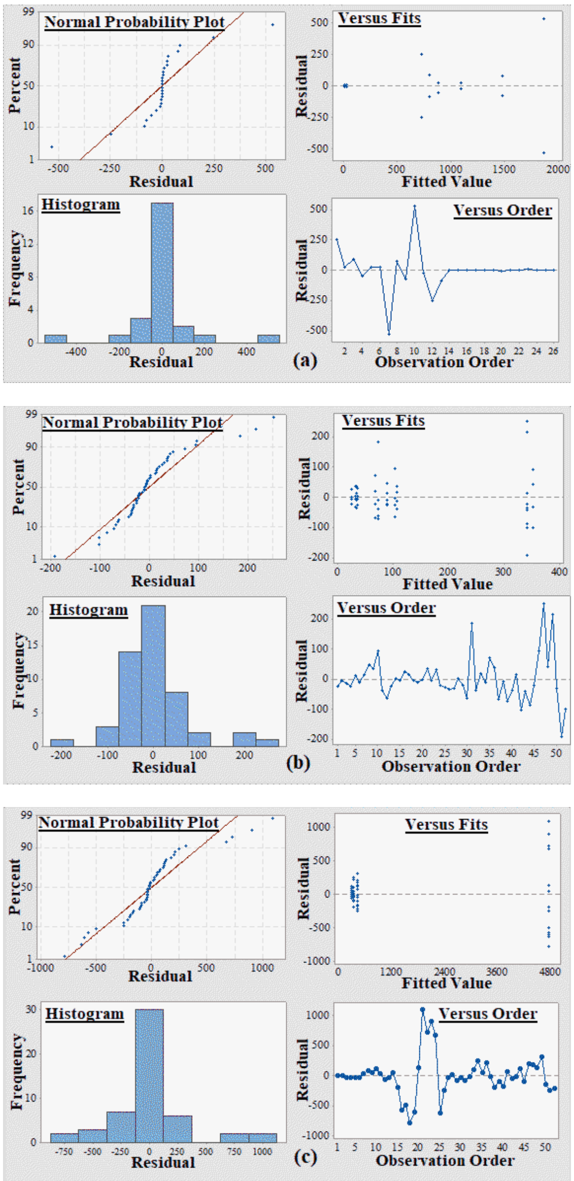

Fig. 3. Residual analysis of web-offset printing machine for a) MOT, b) MDT& c) MIT

Table 4
ANOVA test of web-offset printing machine for a) MOT, b) MDT & c) MIT

Variation	Level	df	SS	MS	F-calculated	F-Critical	p-value	Remark
(a) MOT (in minute) for Web-offset Printing Machine								
PO	4	3	9236553	3078851	59.85	3.344	<.00001	significant
Speed	3	2	236054	118027	2.29	3.739	0.137	not significant
Interaction	–	6	403968	67328	1.31	2.848	0.316	not significant
Error	–	14	720198	51443				
Total	–	25	10699289					
(b) MDT (in minute) for Web-offset Printing Machine								
Breakdown type	4	3	795176	265059	38.89	2.839	<.00001	significant
Speed	3	2	703	352	0.05	3.232	0.95	not significant
Interaction	–	6	4621	770	0.11	2.336	0.994	not significant
Error	–	40	272643	6816				
Total	–	51	1078507					
(c) MIT (in minute) for Web-offset Printing Machine								
Non-productive time	2	1	67335460	67335460	566.88	4.043	<.00001	significant
Man/Machine made	2	1	58820058	58820058	495.19	4.043	<.00001	significant
Interaction	–	1	62496116	62496116	526.14	4.043	<.00001	significant
Error	–	48	5701568	118783				
Total	–	51	194353203					

Table 5
ANOVA test of CTP1 for a) MOT, b) MDT& c) MIT

Variation	Level	df	SS	MS	F-calculated	F-Critical	P-Value	Remark
(a) MOT (in minute) for CTP1								
PO	2	1	5837.2	5837.24	9.67	5.12	0.013	significant
Speed	2	1	3879.3	3879.31	6.42	5.12	0.032	significant
Interaction	–	1	44.1	44.14	0.07	5.12	0.793	not significant
Error	–	9	5435	603.89				
Total	–	12	15279.7					
(b) MDT (in minute) for CTP1								
Breakdown type	3	2	353741	176871	49.32	3.285	<.00001	significant
Speed	2	1	16	16	0.004	4.139	0.948	not significant
Interaction	–	2	6648	3324	0.93	3.285	0.406	not significant
Error	–	33	118333	3586				
Total	–	38	584768					
(c) MIT (in minute) for CTP1								
Non-productive type	2	1	61022722	61022722	29684.57	4.043	<.00001	significant
Man/Machine made	2	1	67576920	67576920	32872.87	4.043	<.00001	significant
Interaction	–	1	62939802	62939802	30617.14	4.043	<.00001	significant
Error	–	48	98674	2056				
Total	–	51	191638118					

Table 6
ANOVA test of CTP2 for a) MOT, b) MDT& c) MIT

Variation	Level	df	SS	MS	F-calculated	F-Critical	p-value	Remark
(a) MOT (in minute) for CTP2								
PO	2	1	3086.7	3086.7	5.89	5.12	0.038	significant
Speed	2	1	37	36.96	0.07	5.12	0.797	not significant
Interaction	–	1	790.2	790.18	1.51	5.12	0.251	not significant
Error	–	9	4720.1	524.45				
Total	–	12	13118.9					
(b) MDT (in minute) for CTP2								
Breakdown type	3	2	18636.2	9318.1	10.55	3.28	<.00001	significant
Speed	2	1	885.7	885.7	1	4.14	0.324	not significant
Interaction	–	2	6712.7	3356.3	3.8	3.28	0.033	significant
Error	–	33	29154.7	883.5				
Total	–	38	77162.8					
(c) MIT (in minute) for CTP2								
Non-productive type	2	1	61890248	61890248	29477.13	4.043	<.00001	significant
Man/Machine made	2	1	70757557	70757557	33700.45	4.043	<.00001	significant
Interaction	–	1	66688395	66688395	31762.39	4.043	<.00001	significant
Error	–	48	100781	2100				
Total	–	51	199436981					

Table 7
ANOVA test of Exposure Unit for a) MOT, b) MDT& c) MIT

Variation	Level	df	SS	MS	F-calculated	F-Critical	p-value	Remark
(a) MOT (in minute) for Exposure Unit								
PO	2	1	2094	2094	1.72	5.12	0.222	not significant
Speed	2	1	2233	2233	1.83	5.12	0.209	not significant
Interaction	–	1	1125	1125	0.92	5.12	0.362	not significant
Error	–	9	10961	1218				
Total	–	12	16161					
(b) MDT (in minute) for Exposure Unit								
Breakdown type	4	3	1999429	666476	473.45	2.82	<.00001	significant
Speed	2	1	14446	14446	10.26	4.06	0.003	significant
Interaction	–	3	37660	12553	8.92	2.82	<.00001	significant
Error	–	44	61939	1408				
Total	–	51	2083147					
(c) MIT (in minute) for Exposure Unit								
Non-productive type	2	1	62213594	62213594	39700.73	4.043	<.00001	significant
Man/Machine made	2	1	70622308	70622308	45066.64	4.043	<.00001	significant
Interaction	–	1	63648094	63648094	40616.14	4.043	<.00001	significant
Error	–	48	75219	1567				
Total	–	51	196559215					

It is also noteworthy to mention that the distribution of residuals in histograms shows some deviations from normality because of outliers as shown in the boxplot (Fig. 2). Otherwise the distributions are all skewed similarly. Generally normality assumption concerns the residuals not the raw data. Though the assumption of homogeneity of variances is slightly violated because of little amount of outbound points, this assumption is considered for statistical significance in two-way ANOVA.

Similarly it can also be checked and analyzed the residual or error scenarios of other machines as well. So, in short, residual analysis will uncover the difference between the observed data and predicted fitted data for the MOT, MDT and MIT of all the machines in the printing house out of which residual status for best fitted probability plot and other parameters for only web-offset machine are shown in Figure 3.

SPC Analysis

From ANOVA analysis, significant factors are then listed in Table 8 for press improvement actions. And after proper analysis and hypothesis testing with implementation it can further be focused on the root problems of the press, which is analyzed by SPC method.

The operating time, downtime and idle-time for web-offset printing machine have been analyzed with the help of individual process control chart (I chart) as shown in Figure 4. These individual charts have been developed by using Equation 1 and 2 with the help of MINITAB17. These types of charts are useful to prevent special causes of variation occurring in future. The green line of this SPC control chart shows the average mean downtime or control line in the process of printing machines. It is also demonstrating the existing status of downtime and production output with upper control limit (UCL) and lower control limit (LCL) of press production. These UCL & LCL denoted by red lines represent the interval during which the process can be further improved by taking proper action of maintenance management and risk management of the machines.

It is seen that the upper control limit (UCL) of individual control chart for daily production status of operating time, downtime and idle-time are 399.4 minutes, 181.5 minutes and 1449 minutes. Then lower control limit (LCL) for operating time and downtime are zero whereas LCL for idle-time is 208 minutes. These SPC charts are helping to identify the present status of the daily planned production time for a given scheduled work or production period of the organization for better productivity. The out bound data points (marked by red points) of operating time and downtime are indicating that the system is not in proper

Table 8
List of significant parameters influencing different machines of printing house

Name of machine	Variations influenced	Significant factors influencing
Web-offset printing machine	MOT	Production output
	MDT	Breakdown type
	MIT	Non-productive time
		Man/Machine made
		Interaction
CTP1	MOT	Production output
		Speed
	MDT	Breakdown type
	MIT	Non-productive time
		Man/Machine made
		Interaction
CTP2	MOT	Production output
	MDT	Breakdown type
		Interaction
	MIT	Non-productive time
		Man/Machine made
		Interaction
Exposure unit	MDT	Breakdown type
		Machine speed
		Interaction
	MIT	Non-productive time
		Man/Machine made
		Interaction

control and needs to take decisions for improvement. Though there is no outbound point of idle-time, it has a scope of reducing the machine idleness.

It is clear that SPC chart guides the manufacturer to the type of action that is appropriate for improving the functioning the production process. Points beyond control limits indicate when special causes should be searched for. The control chart is therefore the prime diagnostic tool for stabilization of the process by the identification and elimination of special causes. All types of statistical tools can aid in active improvement efforts on the process itself by including Pareto analysis, fishbone diagram (FBD) etc. (Kar & Pal, 2022) and recalculated control limits may indicate

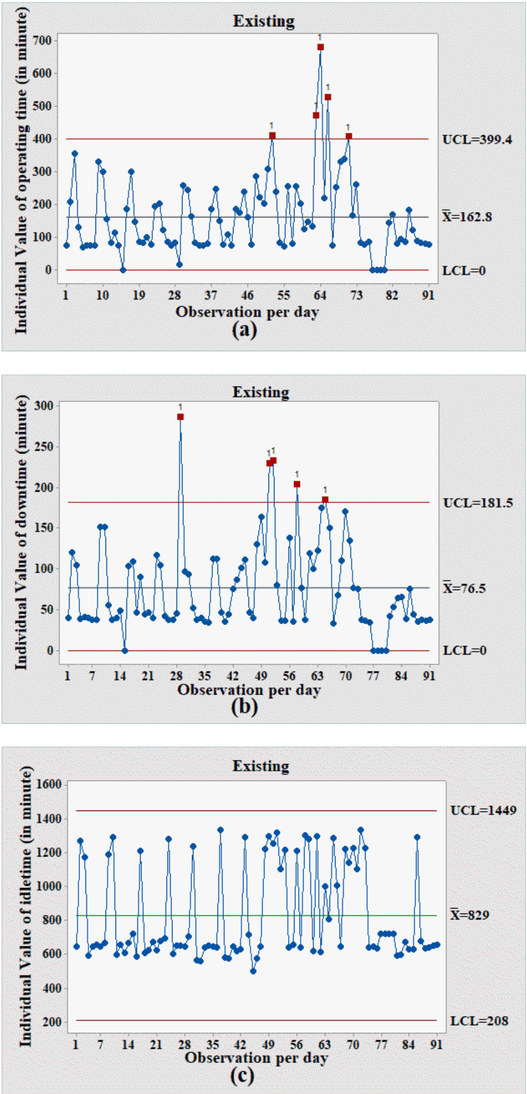

Fig. 4. Individual control chart of (a) operating time, (b) downtime and (c) idle-time for web-offset printing machine

that what kind of success in terms of reduced control limits have been achieved. Therefore, it can be postulated that the special causes of variations can be minimized or eliminated by implementing improved planning of maintenance, which in turn helps in improvement of productivity, effectivity and reliability of the machines of the printing house.

Productivity Improvement

On the basis of the RBM methodology (Kar & Pal, 2019), the efficiency, reliability and other productivity parameters of the machines can be improved. The maximum limit of modification or minimum failure status or risk zones of the machines can be quantified by this quantitative approach called risk-based maintenance (RBM) methodology. However, the improvement of productivity can be accomplished by using the basis of maximum quantified reduction of downtime and corresponding failure number of all the machines in the printing house.

The modified parameters of the machines under the study are shown in Table 9 and these have been calculated by considering the fact that the downtime associated with different types of breakdown and idle-time associated with man/machine made etc. can be reduced with the help of modern technology and management system. It is observed that for a web-offset printing machine, the percentage of increment of productivity (in terms of time) and OEE is +5.7616% and +5.7613% respectively, after implementation of maintenance planning, which is quite significant. By increasing OEE of bottleneck, throughput can be significantly increased and as a result it can produce more output with the same resources and assets. Moreover, the results of ANOVA test have also shown that downtime and idle-time associated with different types of breakdown and failures have a strong impact on productivity.

After successful implementation of improved maintenance planning, SPC method is again applied to check the validity of the improved level of UCL & LCL of operating time, downtime and idle-time. The improved effectivity and productivity factors of web-offset printing machine along with reduced risk status is further monitored by the modified I-chart SPC diagram as shown in Figure 5. This SPC chart of operating time, downtime and idle-time are displaying visually the continuous status of production process and quality control after improvement. The improved control limits of operating time are observed. As a result idleness will be affected along with wastage control.

Moreover, Table 10 shows the existing and modified level of defects per million opportunities (DPMO) and sigma level of web-offset machine with an average of thirteen weeks of production. Opportunities or number of possible reasons for producing waste pieces from web-offset machine is here taken as ‘7’ by considering the type of failures during printing. DPMO is measured to determine the sigma level of web-offset machine by using Equation 3.

$$\text{DPMO} = \frac{\text{Number of waste pieces} \times 1000000}{\text{Total Output} \times \text{Opportunity}} \tag{3}$$

Though the sigma values are quite satisfactory but there is some scope of further improvement of DPMO and Sigma values to reach world class manufacturing.

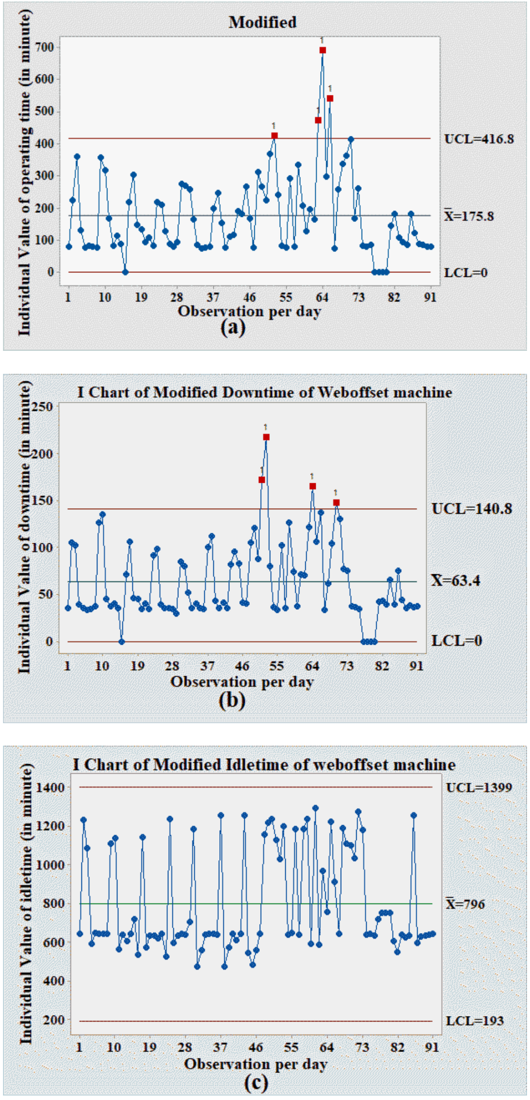

Fig. 5. Individual control chart of modified status of (a) operating time, (b) downtime and (c) idle-time for web-offset printing machine

Similar observations for other machines with improvement of productions can also be developed to provide maximum effective service to customer with the highest degree of utilization of machines in the printing house.

Discussion

From the present study, it is clear that exposure unit is a device that has the highest failure probability therefore less reliability. On the other hand, web-offset machine has the lowest failure probability with high reliability. Analysis of ANOVA test of the machines

Table 9
Modified productivity and effectivity parameters of the machines for total 91 days

Modified Resource	Web-offset printing machine	CTP1	CTP2	Exposure unit
Total Productivity TP (in terms of Cost)	1.5505	1.2085	1.2160	0.9786
Productivity (in terms of time)	0.7196	0.7191	0.8099	0.2620
OEE	0.5374	0.7038	0.6356	0.2583
Utilization factor (UF)	0.2466	0.0530	0.0363	0.1427
Capacity Cushion (CC)	0.7534	0.9469	0.9637	0.8573
TEEP	0.1325	0.0373	0.0231	0.0369
Failure probability	0.4741	0.6535	0.5025	0.7995
Reliability	0.5259	0.3465	0.4975	0.2005
Risk Index (R.I.)	1.4617	1.2519	0.9252	3.9588

also indicates that the exposure unit is in deteriorated conditions due to various significant factors raised during its downtime and idle-time conditions.

The risk indices of different equipment of the printing house under study give a clear understanding of the actual scenarios of the machines. It is also pertinent to mention that exposure unit is having the highest risk index due to maximum failure scenario, whereas web-offset is facing the lowest risk index because of less failure rate. Based on the estimated risk factors of the mentioned equipment, future maintenance planning can be developed by analyzing the root causes of failures for the reduction of the risk of the equipment of the printing house. After modifying the probability of failure for the high risk machines, the suitable preventive maintenance time interval can be re-estimated for improving productivity of the equipment. Improved productivity for web-offset machine is also validated by the analysis of SPC.

This type of approach for improving productivity of the machines along with its validation technique by using ANOVA and Six Sigma method is very useful for the efficient management of the maintenance of the printing equipment to provide its optimal operation.

Table 10
Weekly DPMO and Sigma Level of web-offset machine

	Existing				**Modified**			
Week	Waste pieces	Total output	DPMO	Sigma Level	Waste pieces	Total Output	DPMO	Sigma Level
1	5779	531216	1554.116	4.457	3828	529265	1033.239	4.581
2	7125	621170	1638.613	4.440	5086	619131	1173.534	4.542
3	7925	445925	2538.864	4.302	4613	442613	1488.885	4.470
4	6099	437037	1993.620	4.379	2972	433910	978.478	4.597
5	5640	479791	1679.303	4.433	4289	478440	1280.650	4.516
6	5421	486460	1591.968	4.449	3658	484697	1078.140	4.568
7	8313	695723	1706.960	4.428	5696	693106	1174.011	4.542
8	11602	804593	2059.959	4.369	6484	799475	1158.617	4.546
9	10089	731116	1971.350	4.383	7687	728714	1506.960	4.466
10	17813	1257604	2023.462	4.374	12261	1252052	1398.961	4.489
11	4474	576338	1108.972	4.559	4099	575963	1016.682	4.585
12	2395	266342	1284.600	4.515	1625	265572	874.124	4.630
13	3511	363314	1380.545	4.493	3511	363314	1380.545	4.493

Managerial and Theoretical Implication

The results of the analysis show that failure rate and risk factor of the machines increases with the increase of machine downtime, idle-time and number of failures occurred. It is observed that improved productivity and effectivity of printing machines can be achieved by adopting the proposed risk-based methodology in combination with statistical techniques, such as ANOVA and six-sigma. The downtime of industrial equipment accounts for heavy losses that can be reduced by making accurate predictions of MOT, MDT and MIT using internal productivity data. Recent 'Industry 4.0' is able to handle the continuous monitoring of industrial machines, storing sensors data in real time and maintenance history. With the evolution of technology, such as internet of things (IoT), big data and machine learning, it is possible to connect manufacturing devices to networks to send and exchange data. The printing presses are one of such production units where meeting deadline is of utmost importance hence any unforeseen failure or downtime can affect detrimentally. Therefore, efficient monitoring of productivity data with any intelligent system is quite necessary. It can be postulated that the integration of risk-based maintenance methodology, statistical approach of ANOVA & six-sigma and data science will be able to identify the loop holes in production management and maintenance management (Garcia & Garcia, 2019) to perform better productivity planning.

The present work, therefore, can be extended towards the hardware implementation of monitoring the productivity data of machines and prediction of failure and risk factor using machine learning algorithm. Considering the findings and scopes of the future work the proposed approach may be considered as an important dimension to the emerging field of productivity improvement of machines in any production unit.

Conclusion

The proposed methodology for productivity improvement can be applied to several areas of production process. The basic resources needed for the efficiency improvement include the time during which the production process of the facility takes place, as well as the amount of funds and energy expended. By using this technique, it is possible to simulate the present scenario and analyze their impact on selected factors such as OEE, utilization factor, failure probability, risk index and sigma level without interacting the production line. The outputs for the simulation can then be implemented directly to the production line. The proposed approach has been framed by analyzing the results of ANOVA tests, which helps to find out the significant influencing factors towards less productivity of the system. The variation of process performance and production output are also analyzed by applying lean six sigma (LSS) and statistical process control (SPC) method, which may help to understand the present production scenario. Risk-based maintenance (RBM) methodology has been used to improve productivity, effectiveness, utilization, failure probability and risk factors of different machines of the printing house, which is also validated and confirmed by the analysis of I-chart.

The present investigation for controlling productivity parameters of the machines in a printing house as a function of combined efficiency of human cognitive system, intelligent machine and also their shared interactions supports not only productivity management but also maintenance management. The future connected with printing industry 4.0 technologies will be in high level automation and implementation of artificial intelligence elements and tools for collecting, storing and processing big data. And for this perfect data collection and digitization are needed.

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ANNEXURE: Basic representative data of the machines under study

Table A.1. Basic data of web-offset printing machine a) MOT, b) MDT & c) MIT
a) MOT (in minute) for Web-offset machine

No of week	OT (in minute)		Level of speed
	OT for PO of good pieces	OT for PO of waste pieces	
wk1	980	16	High
wk2	1124	15	High
wk3	890	18	Low
wk4	832	14	Medium
wk5	910	11	Medium
wk6	910	15	Medium
wk7	1331	17	Medium
wk8	1553	23	Low
wk9	1404	20	Low
wk10	2393	35	Medium
wk11	1071	15	High
wk12	482	10	High
wk13	714	10	Low

b) MDT (in minute) of Web-offset printing machine

No of week	MDT (in minute)				Level of speed
	Breakdown due to LDUL	Breakdown due to TR	Breakdown due to OTMB	Breakdown due to CSOD	
wk1	78	39	0	305	High
wk2	100	31	35	355	High
wk3	92	52	45	250	Low
wk4	67	48	10	300	Medium
wk5	102	28	257	255	Medium
wk6	80	24	35	320	Medium
wk7	122	26	87	445	Low
wk8	137	70	62	592	Medium
wk9	142	21	138	393	Low
wk10	199	67	70	556	High
wk11	69	5	0	320	Low
wk12	39	10	25	150	High
wk13	64	0	0	240	Medium

c) MIT (in minute) of Web-offset printing machine

No of week	MIT (in minute)			
	Schedule stop		Un-schedule stop	
	Manmade	Machine-made	Manmade	Machine-made
wk1	270	305	4792	251
wk2	270	355	4550	493
wk3	240	250	4173	381
wk4	240	300	4249	406
wk5	240	255	3957	544
wk6	240	320	4136	321
wk7	300	445	4872	626
wk8	360	592	5843	601
wk9	330	393	5472	557
wk10	390	556	5650	738
wk11	300	320	5420	268
wk12	210	150	4114	172
wk13	240	240	4492	206

Table A.2. Basic data of CTP1 for a) MOT, b) MDT & c) MIT
a) MOT (in minute) for CTP1

No of week	OT (in minute)	Level of PO	Level of speed
wk1	177	OT for high PO	Medium
wk2	204	OT for medium PO	High
wk3	183	OT for high PO	Medium
wk4	163	OT for medium PO	High
wk5	174	OT for medium PO	Medium
wk6	165	OT for medium PO	Medium
wk7	207	OT for high PO	Medium
wk8	247	OT for high PO	High
wk9	204	OT for high PO	Medium
wk10	220	OT for high PO	High
wk11	189	OT for high PO	Medium
wk12	99	OT for medium PO	Medium
wk13	162	OT for medium PO	Medium

b) MDT (in minute) for CTP1

No of week	MDT (in minute)					
	Breakdown for LDUL	Level of speed	Breakdown for SMBSM	Level of speed	Breakdown for PPD	Level of speed
wk1	69	Medium	15	Medium	184	Medium
wk2	80	High	9	High	183	High
wk3	75	Medium	35	Medium	354	Medium
wk4	62	High	140	High	154	High
wk5	71	Medium	0	High	161	Medium
wk6	66	Medium	0	High	287	Medium
wk7	84	Medium	0	Medium	173	Medium
wk8	94	High	0	Medium	412	High
wk9	75	Medium	0	Medium	354	Medium
wk10	77	High	0	Medium	225	High
wk11	79	Medium	2	Medium	364	Medium
wk12	40	Medium	0	Medium	274	Medium
wk13	63	Medium	0	Medium	369	Medium

c) MIT (in minute) of CTP1

No of week	MIT (in minute)			
	Schedule stop		Un-schedule stop	
	Manmade	Machine-made	Manmade	Machine-made
wk1	210	4569	122	84
wk2	210	4537	129	89
wk3	210	4537	123	110
wk4	210	4465	128	202
wk5	210	4585	125	71
wk6	210	4599	133	66
wk7	210	4539	124	84
wk8	210	4489	129	94
wk9	210	4551	123	75
wk10	210	4533	126	77
wk11	180	4590	106	81
wk12	120	4781	69	40
wk13	210	4605	138	63

Table A.3. Basic data of CTP2 for a) MOT, b) MDT & c) MIT
a) MOT (in minute) for CTP2

No of week	OT (in minute)	Level of PO	Level of speed
wk1	125	OT for medium PO	Medium
wk2	124	OT for medium PO	High
wk3	125	OT for medium PO	Medium
wk4	185	OT for high PO	Medium
wk5	140	OT for high PO	High
wk6	150	OT for high PO	Medium
wk7	155	OT for high PO	Medium
wk8	205	OT for high PO	Medium
wk9	150	OT for high PO	Medium
wk10	155	OT for high PO	Medium
wk11	146	OT for high PO	High
wk12	70	OT for medium PO	Medium
wk13	115	OT for medium PO	Medium

b) MDT (in minute) for CTP2

No of week	MDT (in minute)			Level of speed
	Breakdown for LDUL	Breakdown for SMBSM	Breakdown for PPD	
wk1	28	0	90	Medium
wk2	31	10	52	High
wk3	32	15	85	Medium
wk4	45	0	109	Medium
wk5	28	165	71	High
wk6	39	0	100	Medium
wk7	36	0	119	Medium
wk8	48	0	157	Medium
wk9	36	13	106	Medium
wk10	34	0	90	Medium
wk11	34	0	111	High
wk12	15	10	43	Medium
wk13	27	0	57	Medium

c) MIT (in minute) of CTP2

No of week	MIT (in minute)			
	Schedule stop		Un-schedule stop	
	Manmade	Machine-made	Manmade	Machine-made
wk1	210	130	4677	28
wk2	210	146	4664	41
wk3	210	133	4658	47
wk4	210	146	4600	45
wk5	210	154	4497	193
wk6	210	136	4641	39
wk7	210	133	4639	36
wk8	210	144	4577	48
wk9	210	135	4631	49
wk10	210	133	4641	34
wk11	180	112	4681	34
wk12	120	82	4825	25
wk13	210	141	4688	27

Table A.4. Basic data of Exposure Unit for a) MOT, b) MDT & c) MIT
a) MOT (in minute) for Exposure unit

No of week	OT (in minute)	Level of PO	Level of speed
wk1	169	OT for high PO	Medium
wk2	174	OT for high PO	Medium
wk3	170	OT for medium PO	High
wk4	174	OT for high PO	Medium
wk5	169	OT for high PO	Medium
wk6	174	OT for medium PO	Medium
wk7	201	OT for high PO	High
wk8	248	OT for high PO	High
wk9	201	OT for high PO	High
wk10	226	OT for medium PO	Medium
wk11	191	OT for medium PO	High
wk12	94	OT for medium PO	Medium
wk13	156	OT for medium PO	High

b) MDT (in minute) for Exposure unit

No of week	MDT (in minute)				Level of speed
	Breakdown for LDUL	Breakdown for SMBSM	Breakdown for EBLD	Breakdown for PPD	
wk1	38	5	0	319	Medium
wk2	38	0	10	510	Medium
wk3	38	8	8	366	Medium
wk4	39	15	0	402	Medium
wk5	38	0	0	362	Medium
wk6	40	0	0	488	High
wk7	45	15	0	428	High
wk8	59	7	12	596	High
wk9	47	8	24	505	High
wk10	55	22	29	492	Medium
wk11	41	0	26	639	High
wk12	21	0	17	412	Medium
wk13	34	8	2	559	High

c) MIT (in minute) of Exposure unit

No of week	MIT (in minute)			
	Schedule stop		Un-schedule stop	
	Manmade	Machine-made	Manmade	Machine-made
wk1	210	85	4618	43
wk2	210	89	4608	48
wk3	210	84	4606	54
wk4	210	87	4602	54
wk5	210	101	4623	38
wk6	210	81	4616	40
wk7	210	83	4569	60
wk8	210	82	4504	78
wk9	210	88	4550	79
wk10	210	85	4498	106
wk11	180	72	4602	67
wk12	120	47	4788	38
wk13	210	91	4630	44