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Productivity Infrastructure in Security Printing: A Lean Manufacturing Approach

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Abstract

This paper has identified lean manufacturing techniques that contribute to improved productivity in security printing. Equipment efficiency for lithographic printing, directly influences productivity of a security printing department's processes and lean techniques such as Single Minute Exchange of Die (SMED) and Total Productive Maintenance (TPM) were found to be capable of improving productivity. Regression results revealed a significant relationship ($p = 0.028$) between Q28_19 (Use of latest printing technology) and Q13 (printing machines operating at optimum level). Adopting the latest printing technology could improve changeover time during printing, ensuring that machines are operated optimally. The dataset used in this research was obtained from a quantitative data collecting process based on questionnaires from respondents selected using convenience sampling. Collected data were analysed using Statistical Package for the Social Sciences (SPSS). The study demonstrated the impact of lean tools, principles and activities on the performance of printing machines, bearing an influence on overall productivity of the printing department. The study further explained the significance of the relationship between lean activities and the level at which machines operate.

Keywords

Lithographic Printing, Lean Manufacturing, Productivity, Quality, Security Printing

1. Introduction

The printing industry falls under the manufacturing sector which is the fourth largest industry, contributing in the region of 14% of the South African gross domestic product (GDP). Higher productivity is associated with higher GDP (Rodrik

& Stiglitz, 2024). Printing companies play a major role in the country's economy (Mamudu et al., 2024). Identifying various means capable of enhancing printing processes has been the goal (Mamudu et al., 2024) for practitioners and researchers in the field of manufacturing (Rakobela et al., 2022). Optimising organisational means capable of improving printing processes has become one of the many competitive strategies of choice adopted to gain a competitive edge and remain sustainable (Komolafe et al., 2024). Effective production planning and effective equipment utilisation are some of those means needed to improve productivity for the printing department to remain competitive in the South African printing industry (Movaheda & Khakbazan, 2025). Printing activities are labour intense and motivating employees is critical to ensure high standard performance of the printing department. Shop floor layout has a significant impact on the performance of the printing system, lean oriented layout is vital for productivity improvement through seamless flow of people and materials (Leksic et al., 2020). Printing machines that are effectively utilised determine the accomplishments of the printing system. The level of technological advancement of the printing machines therefore boosts customer base since customers demand that manufacturing industries should compete globally through the use of technological factors (Mtshali et al., 2018; Nyakala et al., 2023; Tripathi et al., 2024). Excessive movement of materials between work centres affects overall productivity of the printing system. Work centres are made up of multiple machines according to their intended use, poor management of these machines negatively impacts productivity (Farmakis et al., 2024). The paper seeks to determine lean techniques that could be used to improve the printing department's productivity and evaluate whether the adoption of lean manufacturing improves the printing department's productivity.

2. Literature Review

2.1. Lean Manufacturing in the Printing Industry

A variety of studies have responded to the issues surrounding productivity in the manufacturing environment, including the printing industry. With lean manufacturing's quest for waste elimination approach, reduction of lead times; elimination of waste and improvement of business performance are realised (Ferrazzi et al., 2025; Bhadu et al., 2025). Mady et al. (2020) argued that adopting lean manufacturing significantly reduce no-value adding activities. Lean manufacturing is a common practice in manufacturing in pursuit of competitive edge and being responsive to customer demands of high-quality printed materials (Ngadono et al., 2020). A variety of lean tools are used to enhance performance of manufacturing organisations as argued by Palange and Dhatrak (2021), however, the lack of published material related to lean manufacturing in the South African printing systems remains a concern. Those lean tools include single-minute-exchange-of-die (SMED); 5S; cause and effect diagrams; value stream mapping (VSM); kaizen; total quality management (TQM) and total productive maintenance (TPM). Printing systems' survival and success are dependent on improved turnaround times which has a positive impact on overall cost. Through its focus on reducing change over time in a production process, SMED shorten lead times for printed materials (Junior et al., 2022). Reducing set up time enables meeting customer expectations and increasing machine availability as argued by Kose et al. (2022). The use of older conventional machines presents a disadvantage whenever a changeover takes place due to extended times taken to complete such a change over (Mohammad et al., 2024). It is for this reason that manufacturing organisations are adopting the SMED technique to reduce change over time. A variety of authors argue that 5S is a philosophy focusing on simplifying work environment; effective organisation of the workplace and reduction of waste, improving safety and quality (David et al., 2024; Solís-Quinteros et al., 2024). Through its five-step approach, 5S was implemented to make workplace tidy. 5S is used as a business improvement tool irrespective of the size and organisational sector where employee involvement is of significant importance to successfully implement this approach and prevent it being regarded as just a "spring cleaning" attempt (Deepan et al., 2020). To achieve effective, efficient and organised work centres and improve productivity; reduce costs and workplace accidents; improve quality standards, printing departments could use 5S.

2.2. Lean Tools and Principles and Their Applications

Formalising the application of the famous Five Why's method resulted to root-cause-analysis (RCA), serving as a foundational paradigm of widely used and highly refined business processes with high process maturity (Camilleri, 2024). RCA is a systematic approach used to identify root causes of specific events (Lin et al., 2020; De Jesus Santos et al., 2022). Kumah et al. (2024) suggested that several tools that have emerged from the literature as generic standards for identifying root causes include cause-and-effect diagram. Cause-and-effect diagram provides an orderly way of looking at effects and the causes that contribute literature effects (Sunadi et al., 2020). Listing all possible causes and effects on the diagram and then focusing on each cause per category until all of them are dealt with, define the origin of the problem such as low productivity. VSM has become one of the most popular and widespread development tools within the lean community as a system level tool that maps material and information flows within an organisation or through the value chain, analyse and eliminate waste in manufacturing to ensure a smooth flow of operational processes (Hedlund et al., 2020; Mehta & Dave, 2020). The use of VSM has enabled lean manufacturing to contribute to the attainment of printing division's objectives which include profitability; efficiency; customer satisfaction; high quality products and responsiveness. Ullah et al. (2024) further suggested that VSM assist printing systems address sustainability challenges that they are facing due to the growth in customers' demands. In times of innovation, rapid economic development and desire for competitive edge, printing departments try to improve quality of printed materials, optimise printing processes and reduce costs associated with running a printing department. As a philosophy that seeks to continuously improve, kaizen could be used to solve challenges related to work through its support of employee involvement. Customer satisfaction is an important concept in marketing and consumer research and it is common opinion that if customers are satisfied with their printed materials, they are more likely to continue printing with the same printing department. Kaizen methodology has a number of related and often overlapping practices which include TPM; just-in-time; elimination of seven wastes; automation; plan-do-check-act (PDCA) cycle and poke-yoke (Yohannes, 2020). TQM is an organisational approach that began in the 1950's and has consistently turned out to be better known following the mid 1980's (Singh, 2024: p. 2232). TQM can be defined as an approach to managing organisations which emphasises continuous improvement of quality and customer satisfaction, entails the application of tools and approaches for managing organisational processes (Singh, 2024: p. 2232). Through the adoption of TQM, a printing department could achieve customer satisfaction; employee involvement and continuous improvement (Putra et al., 2024). Evolutions in the business world have made quality a priority for the individual manufacturing organisations, including printing departments, resilience and competitiveness. Lepistö et al. (2024) argued that printing departments should undertake TQM as a journey rather than a destination in pursuit of customer satisfaction, enabling continuous improvement which will continuously influence customer satisfaction levels. Like other organisations that are enjoying TQM benefits, the printing department could also strengthen its performance and competitive advantage by adopting the philosophy (Nehme et al., 2024). As a result of global competition and ever-changing customer demands, many printing departments have been driven to enhance their performance through effective management programs such as TPM. To improve their competitive position globally, more printing departments are turning to proactive solutions like TPM which plays a pivotal role in enhancing global competitiveness.

2.3. Understanding the Integrity of Production and Quality Systems

The printing department has a variety of machines needed to complete printed products which include desktop publishing; printing plate-making machine; printing machines; finishing machines and dynamic packaging machines. These machines require good care through proper maintenance so as to improve the integrity of production and quality systems. As a lean tool, TPM has a positive impact on the printing processes (Florez-Cáceres et al., 2024). For it is implemented by all employees, management and operators on the shop floor are involved and allowed to contribute towards the printing department. Total preventative maintenance focuses on the participation of all employees to implement a comprehensive maintenance program for all equipment throughout their life (Guerrero-Telles et al., 2024). Shamim (2025) suggest that creating strong partnership for change between maintenance and production teams by analysing and removing unnecessary maintenance procedures; developing standard counter measures to common problems; reducing the time to repair as well as engaging operators in the asset care could have a lasting positive impact on productivity of the printing department. TPM could further increase productivity level; decrease defects and clients claims; decrease labour and maintenance costs; reduce inventory levels; eliminate environmental safety violations and increase employee involvement. Eliminating 70% - 75% of downtime associated with equipment failure help increase productivity by 20% - 25% (Okpala et al., 2025; Gomaa, 2025). The opportunity cost of lost production; extension of fixed costs; cost of maintaining an increased number of spares as a result of the failure and the cost of maintaining redundant equipment to mitigate the effects of possible lost production represent economic consequences of a printing system failure.

3. Research Methodology

The core methodology used in this paper is premised on the quantitative approach of data gathering. For data collection, questionnaires were distributed to employees within the Directorate: Security Printing of the printing department. The questionnaire was developed after lengthy consideration of literature focusing on the research objective (Sekhon et al., 2022). The developed questions were answered by managers; supervisors; team leaders and shop floor personnel directly involved in the production of security documents. The questionnaire used a five-point Likert scale to ensure higher statistical variability among survey responses. Convenience sampling as a non-probability research method was utilised owing to its applicability to subjectively choose people who are willing to participate without strict criteria and that are readily available (Zickar & Keith, 2023). The study used Slovin's equation to calculate the sample size (n) given that the population size (N) of 110 and the desired margin of error (e) of 0.05 (Confidence level of 95%) were known. Using Slovin's equation, the sample size was found to be 86.27, equivalent to 87 participants. The study collected and analysed 100 valid responses out of the 110 questionnaires distributed to all employees within the Directorate: Security Printing. The results obtained from various questionnaire respondents were presented in the form of numerical data and thereafter analysed through the use of statistical tools. The data collected were loaded into the statistical package for social sciences (SPSS) software programme for analysis. The statistical techniques used to analyse data were exploratory factor analysis, confirmatory analysis, multiple regression, correlation and analysis of variance.

4. Results and Discussion

The questionnaire, as a research instrument, was used to collect data and it was divided into 3 sections which were demographics; productivity investigation and lean manufacturing as an approach in productivity improvement. Sections are reported below sequentially.

4.1. Demographics

Table 1 presents that 38% of the participants hold a matric or below followed by 31% of the participants who hold a diploma. Results further showed that 13% of the participants hold a university degree with another 13% holding a postgraduate qualification. Participants were spread across a variety of occupations including senior management service (SMS) accounting for 2.1%; middle management accounting for 4.2%; junior management accounting for 2.1%; artisan foreman (Team Leaders) accounting for 8.3%; artisans accounting for 32.3%; printers' assistants accounting for 46.9%; material planner accounting for 2.1% and printing planner accounting for 2.1%.

Table 1. Demographics-level of education and occupation.

Level of Education		Frequency	Valid Percent
Valid	Matric and below	38	38.0
	National Diploma	31	31.0
	University Degree	13	13.0
	Postgraduate	13	13.0
	Other (Please specify)	5	5.0
	Total	100	100.0
Occupation		Frequency	Valid Percent
Valid	Senior Manager (SMS)	2	2.1
	Middle Manager (Deputy Director)	4	4.2
	Junior Manager (Assistant Director)	2	2.1
	Artisan Foreman	8	8.3
	Artisan	31	32.3
	Printing planner	2	2.1
	Printers Assistant	45	46.9
	Material planner	2	2.1
	Total	96	100.0
Missing	System	4	
Total		100	

Furthermore, the results revealed that 51 participants have 11 or more years of work experience while 26 participants have 6 - 10 years of work experience as presented in Table 2. Participants with 4 - 5 years of work experience and 2 - 3 years of work experience accounted for 18% and 5% respectively. More participants of the study work within the Branch: Manufacturing accounting for 72.2% with Branch: Operations accounting for 20.6%. The most contributing division was Origination with participants accounting for only 4% of the total study participants as presented in Table 2.

Table 2. Demographics work experience, branch and division within the department.

Work experience in years		Frequency	Valid Percent
Valid	2 - 3 years	5	5.0
	4 - 5 years	18	18.0
	6 - 10 years	26	26.0
	11 or more years	51	51.0
	Total	100	100.0
Branch within department		Frequency	Valid Percent
Valid	Operations	20	20.6
	Manufacturing	70	72.2
	Other (Please specify)	7	7.2
	Total	97	100.0
Missing	System	3	
Total		100	
Division within the department		Frequency	Valid Percent
Valid	Technical planning	5	5.0
	Originations	4	4.0
	Printing	32	32.0
	Finishing	38	38.0
	Other (Please specify)	21	21.0
	Total	100	100.0

4.2. Investigating Productivity

A maximum of 83% of the participants defined productivity as the ratio of output to input.17% of the participants did not know productivity by definition as presented by **Table 3**. 75.8% of the participants believe that the department measured productivity with 24.2% suggesting the department doesn't measure productivity. From the 75 participants that believed the department measured productivity, 45.3% rated the quality of measurement "good" and 32% of those participants rated the quality of measurement as "fair" as presented in **Table 3** below. Responses of 34%, 28.9%, 10.7%, 17.6% and 6.3% of the respondents suggested that the department selected suppliers based on the price, quality, lead time, dependability and flexibility, respectively, denoting that price of service is perceived the decider in choosing service providers. 36% of the participants postulated that the department sometimes participates in productivity improvement programmes while 29% of the participants believed the department rarely participates in productivity improvement programmes as presented in **Table 3**.

Table 3. Productivity knowledge.

Productivity is the ratio of output to input		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	True	78	78.0	83.0	83.0
	False	16	16.0	17.0	100.0
	Total	94	94.0	100.0	
Missing	System	6	6.0		
Total		100	100.0		
Productivity measured		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	75	75.0	75.8	75.8
	No	24	24.0	24.2	100.0
	Total	99	99.0	100.0	
Missing	System	1	1.0		
Total		100	100.0		
Rate of the quality measurement		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Poor	1	1.3	1.3	1.3
	Fair	24	32.0	32.0	33.3
	Good	34	45.3	45.3	78.7
	Very Good	13	17.3	17.3	96.0
	Excellent	3	4.0	4.0	100.0
	Total	75	100.0	100.0	
Basis on which suppliers are selected			Responses		Percent of Cases
			N	Percent	
Valid	Price		55	34.6%	56.1%
	Quality		46	28.9%	46.9%
	Lead Time		17	10.7%	17.3%
	Dependability		28	17.6%	28.6%
	Flexibility		10	6.3%	10.2%
	Other (Please specify)		3	1.9%	3.1%
Total			159	100.0%	162.2%
Productivity improvement part of the department's goals		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	78	78.0	78.0	78.0
	No	22	22.0	22.0	100.0
	Total	100	100.0	100.0	
Department participate in productivity improvement programmes		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	23	23.0	23.0	23.0
	Rarely	29	29.0	29.0	52.0
	Sometimes	36	36.0	36.0	88.0
	Often	5	5.0	5.0	93.0
	Always	7	7.0	7.0	100.0
	Total	100	100.0	100.0	

Only 54% of the participants suggested that machines were running at an optimum level as presented in **Table 4**. Customers and suppliers play a vital role in enhancing the department's productivity. 58% of the participants indicated that customers understand the printing process, while 43.4% of the participants imply that "sometimes" suppliers deliver raw materials on time with only 16% suggesting raw materials were "always" delivered on time. 10% of the participants indicated that customer orders were "always" completed on time. 43.4% of the participants suggested customers amended their orders during production. 61% of the participants believe the department has sufficient capacity to improve productivity.

Table 4. Operational capability.

Printing machines operating at optimum level		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	54	54.0	54.0	54.0
	No	46	46.0	46.0	100.0
	Total	100	100.0	100.0	
Suppliers delivering raw materials on time		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Never	4	4.0	4.0	4.0
	Rarely	17	17.0	17.2	21.2
	Sometimes	43	43.0	43.4	64.6
	Often	19	19.0	19.2	83.8
	Always	16	16.0	16.2	100.0
	Total	99	99.0	100.0	
Missing	System	1	1.0		
Total		100	100.0		
Customer understanding of printing process		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	58	58.0	58.0	58.0
	No	42	42.0	42.0	100.0
	Total	100	100.0	100.0	
Customer orders completed on time		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Never	10	10.0	10.0	10.0
	Rarely	17	17.0	17.0	27.0
	Sometimes	38	38.0	38.0	65.0
	Often	25	25.0	25.0	90.0
	Always	10	10.0	10.0	100.0
	Total	100	100.0	100.0	

Continued

	Customers amending their orders during production	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	4	4.0	4.0	4.0
	Rarely	31	31.0	31.3	35.4
	Sometimes	43	43.0	43.4	78.8
	Often	15	15.0	15.2	93.9
	Always	6	6.0	6.1	100.0
	Total	99	99.0	100.0	
Missing	System	1	1.0		
Total		100	100.0		
	Sufficient capacity to improve productivity	**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	61	61.0	61.0	61.0
	No	39	39.0	39.0	100.0
	Total	100	100.0	100.0	

A variety of lean tools could be adopted to improve productivity of the department. The study identified SMED as the lean tool with a significant relationship with printing machines operating level as supported by a significance level of 0.013 depicted in the Chi-Square test result in **Table 5** (Pallant, 2020).

Table 5. Chi-Square test results.

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.578[a]	1	0.006		
Continuity Correction[b]	6.195	1	0.013		
Likelihood Ratio	8.253	1	0.004		
Fisher's Exact Test				0.008	0.005
Linear-by-Linear Association	7.495	1	0.006		
N of Valid Cases	92				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.22.

b. Computed only for a 2 × 2 table

Exploratory factor analysis is defined as a data screening tool used to reduce a data set to smaller variables and to establish interrelationships between a set of variables (Pallant, 2020). To establish construct validity and determine factors affecting productivity, a principle components analysis was carried out. Exploratory factor analysis was conducted by means of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of Sphericity. The retention of components was decided upon using the Kaiser's eigenvalue of greater than 1 criterion which specifies that all components with eigenvalue above 1 are retained in the solution. Exploratory factor analysis was conducted on lean tools; lean tools' usefulness and lean activities a company can perform. The KMO measure of sampling adequacy is 0.802 which is considered "very good" for proceeding with factor analysis (Tabachnick & Fidell, 2013). Bartlett's Test of Sphericity shows Chi-Square value of 4341.554 with 861 degrees of freedom and significance level of 0.000. To indicate that the correlation matrix is not an identity matrix and that there are significant correlations among the variables, the p-value is less than 0.05 as presented in **Table 6**.

Table 6. KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.802
Bartlett's Test of Sphericity	Approx. Chi-Square	4341.554
	df	861
	Sig.	0.000

The amount of variance in each variable that is accounted for by the extracted factors is described by the communalities. Initial communalities were set at 1.000 for each variable, indicating that all variables' variances were assumed to be accounted for by the initial solution. To indicate how much the variance of each variable can be explained by the factors extracted in the analysis, the extraction communalities vary. Values ranged from 0.406 for Q28_14 suggesting that less than half of the variance in this variable was explained by the extracted factors to 0.909 for CC4 demonstrating a high degree of explained variance. Indicating that more of the variance was captured by the model, reflecting better suitability of the data for factor analysis, higher values were preferred. Furthermore, total variance explained by each component was derived from a principal component analysis. Total variance that each component explains before extractions represented by the eigenvalues. A clearer understanding of the variance accounted for by each component after rotation is provided by the rotation sums of squared loadings which help interpret components. The first component at 27.37% accounts for the largest share of variance with subsequent components accounting for progressively less variance percentage as presented in the scree plot below (**Figure 1**).

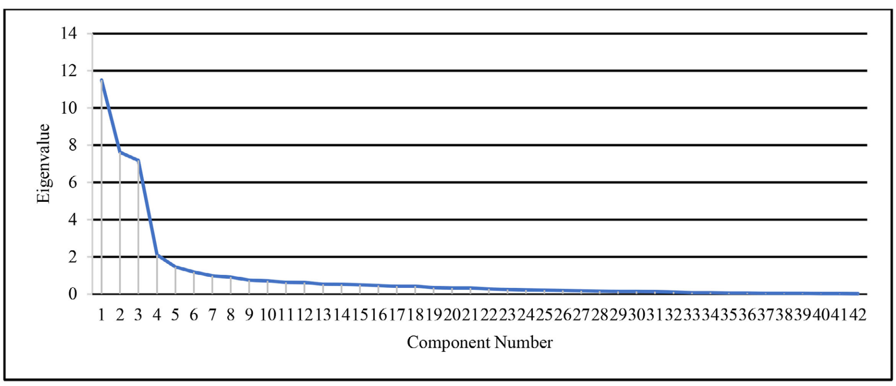

Figure 1. Scree plot.

The rotated component matrix from a principal component analysis with varimax rotation detailed how various items load on the 5 identified components. By presenting the relationship between each variable and prospective underlying factor they represent, rotated component matrix interpreted the factors. Component1 dominated by variables related to lean tools with high loadings ranging from 0.782 to 0.917, indicating a strong relationship of these variables with this component. Component 2 dominated by items related to lean tools' level of usefulness with loadings ranging from 0.674 to 0.934 suggesting a strong contribution to the explanation of usefulness of these lean tools. Component 3 linked with lean activities a company could perform to improve on its performance where variables like Q28_12 have a loading of o.827 representing a strong correlation with machine performance related lean activities the department can perform to improve productivity. Component 4 with loadings ranging from 0.630 to 0.788 represent significant impact of lean activities on productivity improvement. Finally, component where variable like "investing in skills development" have the highest loading at 0.784 indicating a strong correlation with lean activities the department can perform to improve productivity. By making the loadings more distinct across components, the varimax rotation enhanced the interpretability enabling a clearer distinction between what each component represents. This study used construct validity to ascertain the degree of correlation between the decision variables with other measures that were theoretically predicted. Cronbach's Alpha was used to measure decision variables' reliability (Pallant, 2020). The 3 coefficients extracted under the lean manufacturing scale, which were lean tools' usefulness; lean tools and lean activities, had acceptable alpha values of 0.949, 0.965 and 0.948 respectively, indicating sufficient reliability and suggesting a strong relationship between the variables used in the security documents printing. Logistic regression analysis was conducted to examine the influence of lean tools on the probability of productivity improving. Results from the analysed data suggested that lean activities significantly impact productivity, either negatively if not applied or positively if applied. With Chi-Square equalling 38.926, df equalling to 8 and $p < 0.001$, presented by Omnibus test of model coefficients table below, the model is statistically significant.

5. Conclusion

This study identified causes of delays experienced within the printing division. Delays resulted in poor machine utilisation, negatively affecting productivity. The regression results revealed the statistical significance of variable Q28 ($p = 0.000214$) in ensuring optimal machine utilisation. Adopting lean activities supported arguments that lean manufacturing reduces delays experienced within the printing division. The study also seeks to determine lean techniques that could be used to improve the printing department's productivity. Regression results revealed a significant relationship ($p = 0.028$) between Q28_19 (Use of latest printing technology) and Q13 (printing machines operating at optimum level). Adopting the latest printing technology could improve changeover time during printing, ensuring that machines are operated optimally. The study evaluated whether the adoption of lean manufacturing improves the printing department's productivity. From the regression analysis, results exposed a statistical significance ($p = 0.000214$) between variables Q28 (lean activities a company can perform to improve productivity) and Q13 (printing machines operating at optimum level). This result supported the idea that lean manufacturing could improve productivity. From the regression analysis, the empirical findings offer significant insights into the factors influencing productivity as presented below with regard to the study objectives. Overall, the regression model explained the significance of the relationship between lean activities and the level at which machines operate. The findings underscore the multifaceted nature of machine performance influenced by lean tools and lean activities that a company can perform to improve productivity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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