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Effect of Total Productive Maintenance Practices on Manufacturing Performance: An Empirical Analysis of Ethiopian Soft Drinks Manufacturing Company

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Abstract

The objective of this study is to investigate the effect of total productive maintenance (TPM) practices on the manufacturing performance of Ethiopian Soft Drinks Manufacturing Company. A self-administered survey questionnaire (seven-point Likert scale) is used for primary data collection. Correlation and regression analysis was performed using SPSS software to identify the effect of the independent variables (TPM practices: autonomous maintenance, planned maintenance, education and training) on the dependent variable (manufacturing performance). The results show that two of the TPM practices (planned maintenance, education and training)have a positive and significant relationship with manufacturing performance and significantly improve manufacturing performance in terms of cost, quality, and delivery.

Keywords:Total Productive Maintenance, Manufacturing, Performance

I. INTRODUCTION

In today's competitive and mature economic environment, many manufacturing plants worldwide face many challenges to achieve world-class manufacturing standards in operations. In addition, market forces are demanding more emphasis on customization, quick delivery, and supply quality [1]. These pressures demand excellent maintenance practices in such a way that machines and processes are available whenever needed and produce the desired products with the required quality level [2].

Reliable equipment, operating at the lowest possible cost is also an essential enabler of profits [3]. One approach to improve the performance of maintenance activities is to implement total productive maintenance (TPM) system. The only proven work culture that promotes and sustains reliable equipment at lower costs is through TPM [3].

Due to the lack of comprehensive studies on TPM strategies or elements in Ethiopia, this paper aims to evaluate TPM practices in one of the Ethiopian Soft Drinks Manufacturing Company. Analysis was done to determine the effect of these TPM practices towards the core competencies or benefits to the manufacturing performance.

II. LITERATURE REVIEW

The goal of TPM is to continuously improve all operational conditions of a production system by stimulating the daily awareness of all employees [4]. The entire edifice of TPM is built and stands on eight pillars which are a focused improvement; autonomous maintenance; planned maintenance; training and education; early-phase management; quality maintenance; office TPM; and safety, health, and environment. TPM paves way for excellent planning, organizing, monitoring, and controlling practices through its unique eight pillar methodology. This eight-pillar implementation plan which is proposed by JIPM results in an increase in labor productivity through controlled maintenance, reduction in maintenance costs, and reduced production stoppages and downtimes [5, 6].

TPM has eight pillars that are aimed at proactively establishing the reliability of machines. One important concept here is that people are the center of this system and must be continuously trained to identify and eliminate waste.It is a system that is based on a clear set of principles and structures and should not be interpreted to be a set of tools or techniques to be applied haphazardly. The eight pillars of TPM [7] are shown in Figure 1.

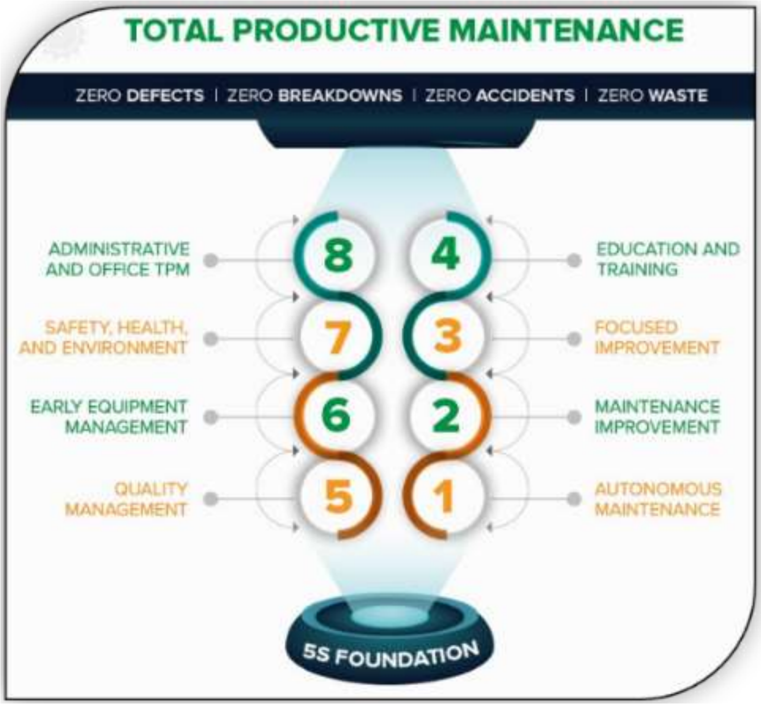

FIGURE 1

TPM PILLARS

TPM brings maintenance into focus as a necessary and vitally important part of the business. It is no longer regarded as a non-profit activity. TPM describes a synergistic relationship among all organizational functions, but particularly between production and maintenance, for the continuous improvement of product quality, operational efficiency, productivity, and safety [4,8]. Nakajima, [9]the father of TPM, has defined TPM as an innovative approach to maintenance that eliminates breakdowns and promotes autonomous maintenance by operators through the day-to-day activities involving the total workforce [10, 11]. TPM implementation methodology provides the organizations with a roadmap to fundamentally transform their shop floor by integrating culture, processes, and technologies. TPM is not a specific maintenance policy, it is a culture, a philosophy, and a new attitude towards maintenance [12]. TPM promotes a holistic view on organizations and their processes and lays equally upon the production equipment and the human beings as well.

a.Manufacturing Performance

Manufacturing performance is explained in terms of various dimensions such as manufacturing plant's labour efficiency [13], machine efficiency, conformance quality [14, 15], manufacturing plant productivity [16, 17], schedule attainment [18], on time delivery [15,19, 20], inventory management [20, 21] production volume flexibility [14, 15] and manufacturing cost efficiency [15,18,22].

Overall, the achievements in manufacturing performance enhance a firm's manufacturing competitive capabilities [15, 23] In this study, the three basic dimensions of manufacturing performance that is studied are cost, quality, delivery [24-26].

This study aims to establish the relationship between TPM practices and manufacturing performance in the Ethiopian Soft Drinks Manufacturing Company (Ethiopia). The literature review indicates a significant positive relationship between TPM practices and manufacturing performance. To understand the relationship of each selected TPM practices on manufacturing performance in Ethiopian Soft Drinks Manufacturing Company, the following hypotheses (H) were developed and tested.

H1: There is a significant positive relationship between identified TPM practices and manufacturing performance of Soft Drinks Manufacturing Company.

H2: There is a significant positive relationship between education and training and manufacturing performance of Soft Drinks Manufacturing Company.

H3: There is a significant positive relationship between autonomous maintenance and manufacturing performance of Soft Drinks Manufacturing Company.

H4: There is a significant positive relationship between planned maintenance and manufacturing performance of Soft Drinks Manufacturing Company.

III. RESEARCH METHODOLOGY

Research methodology is very important as it can guide researchers on what steps needs to be taken to accomplish the objectives of the research [27, 28]. To accomplish the objective of this research study, a questionnaire survey methodology was adopted and was carried out in the selected Soft Drinks Manufacturing Company. This section discusses research design, research instrument, administration of instrument, sample, and data collection procedures used in the study.

a.Research Design

The present research uses a descriptive cross-sectional study design. It is concerned with the analysis of the phenomenon, situation, problem, opinions, demographic information, or issue. The majority of TPM and manufacturing performance studies in the manufacturing sector have employed descriptive cross-sectional study design. In addition to this, the study also employed the survey method, which makes use of a research instrument. This study utilizes face to face survey method as the means of data collection which is commonly used in similar kinds of research.

b.Sampling Method and Sample Size

The sampling frame used for this study is one of the Soft Drinks Manufacturing Company in Ethiopia. A simple random sampling method was used in this study. This method was thought to be appropriate to collect sufficient information from the total population to make statistical inferences.The minimum sample size for a model is based on the maximum number of arrows pointed at any latent variable in the model using the G* Power technique [29, 30]. As per the statistical calculations using G* power 3.1.9.7 software (Fig. 2), the minimum number of respondents needed is 118.

c.Research Instrument and Data Collection Procedure

A self-administered structured instrument was designed in this research based on the literature. The instrument comprises of a non - comparative - itemized rating scale utilizing a seven-point Likert scale, with 1= strongly disagree, 2 = moderately disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = moderately agree, 7 = strongly agree, depending on the type of question. The target respondents for this study were top and middle-level administrators/managers who have sufficient levels of experience and qualifications and therefore, they will be aware of the TPM practices followed in their company. Only 125 useable survey instruments were included for the data analysis.

IV.Variable Measurement

Independent variables (TPM practices): Thirty - eight measurement items consisting of 16 items for autonomous maintenance, 10 items for planned maintenance 12 items for education and training captured the three TPM practices under investigation.Dependent variable (manufacturing performance): Twenty measurement items consisting of 10 items for quality, 8 items for delivery, and 7 items for cost were adopted from previous studies to evaluate manufacturing performance.

IV. RESULTS AND ANALYSIS

Reliability coefficients were initially computed to check the internal consistency of the measuring items of the independent and dependent variables. Face and content validity were also checked followed by the validation of constructs using factor analysis for the study variables. Intercorrelations were computed to understand the variability and interdependence of the subscales derived from the factor analysis. The hypotheses were tested using multiple regression analysis through SPSS - 26 software [31].

a.Face and ContentValidity

Face validity is the mere appearance that a variable is valid. It is the subjective judgment of the correspondence between the individual items and the concept through rating by expert judges [32]. While content validity of an instrument refers to the degree to which the scale items represent the domain of the concept under study. It is also a subjective measure of how appropriate the items seem to various reviewers with some knowledge of the subject matter [33]. In this research, it was argued that the three TPM practices (namely, education and training, autonomous maintenance, planned maintenance) for measuring TPM implementation practices had a face and content validity since the majority of scales/items used in this study are borrowed from established scales that have already been subjected to tests of face and content validity. Moreover, the content validity of the instrument was also ensured through an extensive review of the literature and detailed evaluation by academicians and practitioners. Items were deleted, added, or modified based on their reviews before the analysis.

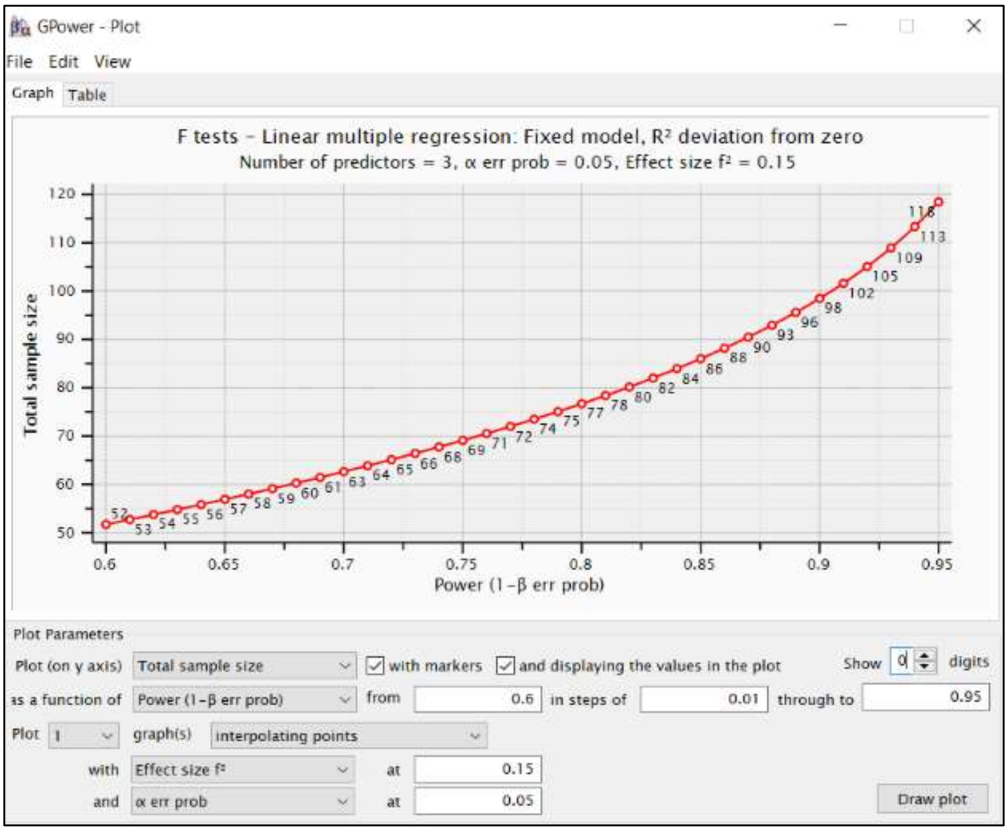

FIGURE 2

TOTAL SAMPLE SIZE REQUIRED USING G-POWER ANALYSIS

b.Construct Validity

Construct validity is the extent to which a measure is related to other measures in a manner consistent with theoretically based concepts [34]. In other words, a measure has construct validity if it measures the theoretical construct or trait that it was designed to measure. This was generally evaluated by factor analysis. The primary purpose of factor analysis is to produce a parsimonious set of new composite dimensions from a large number of variables with a minimum loss of information [32]. Given the nature and requirement of this study, exploratory factor analysis was employed to assess construct validity. The exploratory factor analysis was performed and each scale was subjected to factor analysis separately.

c. Factor Analysis

Factor analysis is a statistical approach that can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their common underlying factors [35]. It is a multivariate data reduction technique, consisting of selecting the method of extracting the components; the number of components to be extracted; and the method of rotation for interpretation of the factors.

In this research study, the principal component analysis method of factor analysis followed by the varimax orthogonal rotation [36] was adopted on three TPM practices comparing 38 items by using SPSS - 26 software. But before going for factor analysis, one of the vital considerations in factor analysis is the sample size of the data [32]. According to Hair et al. [32] a minimum of five subjects per variable is a must for factor analysis or a sample of 100 is acceptable to achieve good results. The sample size of this study is 125. Accordingly, this means that the sample size is adequate and further analysis can be done. To assess the construct validity, factor loadings are obtained for each item. The loadings reflect the strength of the relationship between an item and a particular factor or practice. The higher the loading, the better the representation that particular item has on the factor. In interpreting the factor, Comrey[37] suggested that loading over 0.45 could be considered fair, greater than 0.55 as good, 0.63 as very good, and 0.71 as excellent. For this study, a loading of 0.50 or greater on the factor was considered [32,36,38, 39]. The results for the factor analysis extracted three factors solution with Eigenvalue greater than 1, and TPM practices explains the 66.788 percent (for TPM practices) and 68.060 percent (for manufacturing performance) of the total variance. All the loadings of factor analysis for TPM practices are greater than 0.515 and less than 0.859, which satisfies the minimum loading criteria and all communalities (extraction) are greater than 0.50. Education and training is having more than 45.64 percent of the variance among all factors. Further, the anti-image correlation matrix also revealed that all the measures of sampling adequacy are well above the acceptable level of 0.50. Hence, a model with 3 factors or components might be adequate to represent the data. This suggests that only a relatively small amount of the total variance for each group of variables is associated with causes other than the factor itself. Thus, the results of the factor analysis indicate a high level of the construct validity of the measure.The Kaiser - Meyer - Olkin (KMO) sampling adequacy is about 0.804 percent (for TPM practices), 0.695 percent (for manufacturing performance) which is greater than 0.60 indicate sufficient intercorrelations while the Barlett's test of sphericity was significant (Chi-square = 715.148, *df* = 78, *p* = 0.000 < 0.01; Chi-square = 384.276, *df* = 45, *p* = 0.000 < 0.01).

Initially, there are 16 items for autonomous maintenance, 10 items for planned maintenance 12 items for education and training, 10 items for quality, 8 items for delivery, and 7 items for cost. Total 40 items relating to these factors were due to cross-loading, empty loading, low loadings. Finally, a total of 23 items that are unidimensional and factorially distinct loaded on the constructs were retained for further analysis. The results of factor analysis for TPM practices and manufacturing performance are summarized in Table I.

d. Reliability Test

The reliability study indicates the degree of internal consistency between the multiple variables that make up the scale, in other words, the extent to which the indicators or items of the scale are measuring the same concepts. To guarantee the maximum reliability of the scales proposed, Cronbach's alpha coefficient [40] was calculated for each one-dimensional critical factor identified in the previous section. The reliability of the factors needs to be examined to support any measures of validity that may be deployed [41]. It is the most commonly followed technique to measures internal consistency among a group of items combined to form a single scale and reflects the homogeneity of the scale. Using the SPSS - 26 reliability analysis program software, an internal consistency analysis was performed separately for the items of each TPM practice (three independent variables) and on one dependent variable (manufacturing performance: quality - QUA, delivery - DEL, cost - COS). The alpha values of the study variables are summarized in Table II. The reliability coefficients of the study variables exceeded the minimum acceptable level of 0.70, as per the suggestion made by Nunnally and Bernstein [41]. As can be seen in Table II, the alpha values range from 0.723 to 0.907, thus, providing strong evidence that the scales developed are judged to be reliable [32, 41, 42].

e.Criterion Validity

Criterion-related validity is concerned with the extent to which a measuring instrument is related to an independent measure of the relevant criterion [43] and is sometimes also called external validity or predictive validity. The three TPM practices have high criterion-related validity if these practices are highly and positively correlated with the manufacturing performance of the Soft Drinks Manufacturing Company.

The criterion-related validity of the combined set of three TPM practices was evaluated by examining the Pearson's correlation coefficients (*r*) computed for the three TPM practices and manufacturing performance as a measure of the outcome as well as multiple regression analysis was employed to test the hypotheses (H1 - H4).

TABLE I

ROTATED COMPONENT MATRIX FOR TPM PRACTICES AND MANUFACTURING PERFORMANCE

TPM Practices	Component (Loading > 0.5)			Extraction > 0.5
Independent Variables	EDT	AUT	PLM	
EDT7: Training actions continuous, periodic	0.84			0.80
EDT9: Specific training plans	0.81			0.75
EDT6: Follow-up training needs	0.80			0.78
EDT10: Training plan decided jointly	0.78			0.73
EDT5: Employees sufficient training period	0.75			0.67
AUT8: Employee's cross-trained		0.82		0.69
AUT2: Employee's pride neat, clean		0.77		0.70
AUT11: Deployment cleaning standard		0.68		0.64
AUT3: Company clean all times		0.51		0.52
PLM4: Operator use charts processes			0.73	0.63
PLM8: Maintenance inventory enough			0.73	0.54
PLM10: Employee's maintenance strategy			0.68	0.51
PLM9: Operators portion to maintenance			0.64	0.66
Alpha > 0.70	0.90	0.77	0.74	
% of Variance	45.64	11.07	10.07	

Cumulative % > 50%	45.64	56.71	66.78	
Eigenvalues > 1	5.93	1.43	1.30	
Manufacturing Performance (Quality - QUA, Delivery - DEL, Cost - COS)				
Dependent Variables	QUA	DEL	COS	Extraction
QUA7: Improved customer compliance	0.79			0.67
QUA8: Reduction of customer's returns	0.78			0.66
QUA2: Reduction defects final product	0.76			0.62
QUA9: Improve manufacturing quality	0.76			0.61
QUA3: Reduction claims from the customer	0.59			0.60
DEL7: Delivery dependability		0.85		0.73
DEL6: Delivery accuracy		0.75		0.69
COS6: Work-in-process inventory less			0.85	0.61
COS7: Raw materials inventory less			0.68	0.77
COS5: Finished goods inventory less			0.64	0.80
Alpha > 0.70	0.83	0.72	0.78	
% of Variance	35.53	18.60	13.92	
Cumulative % > 50%	35.53	54.14	68.06	
Eigenvalues > 1	3.55	1.86	1.39	

TABLE II

PEARSON'S CORRELATION AND DESCRIPTIVE STATISTICS ANALYSIS OF TPM PRACTICES AND MANUFACTURING PERFORMANCE, N = 125

Variables		EDT	AUT	PLM	TPMI	MPI
Education and Training (EDT)	*r*	1				
	Sig.					
Autonomous Maintenance (AUT)	*r*	.611**	1			
	Sig.	0.000				
Planned Maintenance (PLM)	*r*	.599**	.625**	1		
	Sig.	0.000	0.000			
Total Productive Maintenance Index (TPMI)	*r*	.868**	.854**	.860**	1	
	Sig.	0.000	0.000	0.000		
Manufacturing Performance Index (MPI)	*r*	.626**	.414**	.492**	.599**	1
	Sig.	0.000	0.000	0.000	0.000	
Mean		4.376	5.100	4.496	4.657	4.706
Standard Deviation (SD)		1.519	1.294	1.403	1.210	0.844

Note:Pearson correlations scale [42]: small: ± 0.1 - 0.3; medium: ± 0.3 - 0.5; large: ± 0.5 - 1.0

**. Correlation is significant at the 0.01 level (2 - tailed)

*. Correlation is significant at the 0.05 level (2 - tailed)

TABLE III

OVERALL MODEL SUMMARY

Model	R	R-Square	Adjusted R-Square	Std. Error of the Estimate	Durbin-Watson
1	.621[a]	0.386	0.367	0.67164	1.746
Change Statistics					
R Square Change	F Change	df1	df2	Sig. F Change	
0.386	20.115	3	96	0.000	
Note: Predictors: (Constant), PLM, EDT, AUT; Dependent variable: MPI					

TABLE IV

MULTIPLE REGRESSION ANALYSIS OF TPM PRACTICES ON MANUFACTURING PERFORMANCE

Model	Independent Variable (s)	Unstandardized Coefficients		Standardized Coefficients	Manufacturing Performance		Collinearity Statistics	
		B	Std. Error	Beta (β)	t	Sig.	Tol. > 0.10	VIF < 10
1	(Constant)	3.054	0.289		10.577	0.000		
	EDT	0.240	0.053	0.471	4.549	0.000	0.598	1.673
	AUT	-0.029	0.069	-0.044	-0.412	0.681	0.553	1.807
	PLM	0.171	0.064	0.267	2.645	0.010	0.629	1.590

Note: Dependent Variable: MPI, Significant at: *$p < 0.05$, * *$p < 0.01$ and ***$p < 0.001$ levels (two - tailed); *t* - value: Not significant, < 1.96, ≥ 1.96 ($p < 0.05$: significance level = 5%), ≥ 2.58: ($p < 0.01$: significance level = 1%), ≥ 3.29 ($p < 0.001$: significance level = 0.1%)

f. Correlation Analysis between the Variables

A Pearson's correlation (r) analysis was carried out in this research study to examine the bivariate relationships among the main variables and to check the presence of multicollinearityproblems.

The correlation matrix in table ii indicated a correlation coefficient between three independent variables and a dependent variable which are measured by using multiple item scales in this research study.As can be seen in table ii, the correlation coefficients for the variables under investigation were relatively high ranging from 0.414 to 0.868, and positively correlated. The overall model summary is shown in Table III and regression analysis results in Table IV.

There was a large effect and significant positive relationship between "education and training - EDT" and "manufacturing performance" ($r = 0.626$, $p < 0.01$)followed by "planned maintenance - PLM" ($r = 0.492$, $p < 0.01$) and "autonomous maintenance - AUT" ($r = 0.414$, $p < 0.01$). It was found that all the TPM practices index (TPMI) had large effect and significant positive correlation ($r = 0.599$, $p < 0.01$) with manufacturing performance index (MPI) (Table III).

Out of 10 correlations, all correlation coefficients are larger than 0.20. The highest coefficient of correlation in this research, however, is 0.868 which is below the cut-off of 0.90 for the collinearity problem. Further, the correlation coefficient between the independent variables and dependent variable was less than 0.90, indicating that the data was not affected by a collinearity problem [32]. Hence, collinearity and multicollinearity do not represent data problems in this research study. The results further indicated that the most important TPM practice affecting manufacturing performance was education and training (i.e., with the highest score of correlation), which goes to prove that where education and training were perceived as a dominant TPM practice, improvements in manufacturing performance levels were significant. Similarly, planned maintenance and autonomous maintenance were also found to affect manufacturing performance as their scores were also high (Table II).The correlation between constructs of TPM and manufacturing performance, mean and standard deviation along with the reliability of each construct has been reported in Table II.

g.Multiple Regression Analysis

Multiple regression is used to investigate the relationship between a single dependent variable (criterion) and several independent variables (predictors or explanatory) at one time [32]. It is employed to test the research hypotheses. In this analysis, a set of independent variables is weighted to form the regression variate (regression equation or model) and that may be used to explain its relative contribution towards one dependent variable [32]. This analysis was undertaken to better understand the relationships between TPM practices and manufacturing performance.

One of the vital considerations in multiple regression analysis is the sample size of the data. According to Hair et al. [32] a sample size to estimate a parameter ratio of 10:1 is adequate to achieve meaningful estimates. The sample size of this study has an estimated parameter ratio of 10.2:1 for the quality performance. Accordingly, it was found that the sample size was adequate. Based on this method, the three main independent variables (TPM practices) and dependent variables (manufacturing performance) were entered using the forced entry or simultaneous regression method.

The details of the overall model summary and multiple regression output are shown in Table III and Table IV respectively. From Table III, the Durbin - Watson index is at 1.746, which lies within the range of 1.50 - 2.50, suggesting that there was no autocorrelation problem in the data [44].

Also, from Table IV, each of the variables had a tolerance (Tol.) value of more than 0.10 and variation inflation factor (VIF) of less than 10 [36]. The finding indicated that the model had no serious multicollinearity problem [32] as also found in Pearson's correlation analysis. This indicated that there is a statistically significant relationship between TPM practices and manufacturing performance. From these analyses, it can be concluded that the multiple regression model of this study meets all the assumptions required to ensure the validity of its significance test [45, 47].

To judge the magnitude of effects in this study, Cohen's rules for effects sizes are used. According to Cohen [42], as cited by [42, 49], R^2(coefficient of determination)between 1.0 and 5.9 percent is considered as small, between 5.9 and 13.8 percent is medium, and above 13.8 percent is large. From Table III, it can be observed that the coefficient of determination (R^2) was 0.386, representing that 38.6 percent of manufacturing performance can be explained by the 3 independent variables. This expresses that TPM can significantly account for 38.6 percent of manufacturing performance. Thus, the effect size for this study is large and H1 was partially supported. The proposed model was adequate as the *F*-statistics $\{F\ (3, 96) = 20.115\}$ was significant at 1 percent level ($p < 0.01$). This indicated that the overall model was a statistically significant and positive relationship between TPM practices and manufacturing performance (Table IV). The results of multiple regression analysis, including the standardized β coefficients and *t*-value significant level, are tabulated and presented in Table V. The results also indicated that there are 2 practices of TPM, namely EDT and PLM which are positively associated with manufacturing performance. The individual model variable revealed that EDT ($\beta = 0.471$, $p = 0.000 < 0.001$) and PLM ($\beta = 0.267$, $p = 0.010 < 0.01$) are directly involved in the improvement of manufacturing performance. Therefore, H1 and H3 were supported. Meanwhile, AUT ($\beta = -0.044$, $p = 0.681 > 0.05$) had no significant effect on manufacturing performance. Hence, H3 is not supported.

V. Conclusion

This research paper has accomplished the stated objectives of the study and analyzed the relationship between the TPM practices and manufacturing performance in the Soft Drinks Manufacturing Company. The study found three TPM practices (autonomous maintenance, planned maintenance, education and training) to be partially influencing the company's manufacturing performance (quality, delivery, cost).

The findings indicated the importance of planned maintenance, education and training for predicting a company's manufacturing performance. Thus, the results of the study reported two practices of TPM that are more significantly associated with the improvement in the company's manufacturing performance and provide evidence of the positive effect of TPM on the company's manufacturing performance. This study provided the effect of TPM on company performance in both qualitative and quantitative terms. Overall, the outcome of this study indicated that the TPM practices were found to be partially correlated with the manufacturing performance of the case company.

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