



Research article

The optimization of overall equipment effectiveness factors in a pharmaceutical company

Okpala Charles Chikwendu^{*}, Anozie Stephen Chima, Mgbemena Chika Edith^{**}

Nnamdi Azikiwe University, PMB 5025, Awka, Anambra, Nigeria

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ABSTRACT

Over the years, the inability of pharmaceutical companies to achieve optimum maintenance of their equipment, and enhanced machine availability for better resource and maintenance utilization, has adversely affected their competitive advantage. The need to adopt a unique production technique that will curb their numerous equipment maintenance challenges, and also re-position them for world-class manufacturing will not only reduce their losses, but will also increase their throughput and profitability. To address a Pharmaceutical firm's maintenance challenges, data were obtained for the Overall Equipment Effectiveness (OEE) factors after Total Productive Maintenance (TPM) implementation in the company. Minitab 16.0 software was used to analyze the data collected, and the results showed that the highest value of 98.90 and 96.39 in the descriptive statistics for the maximum and mean respectively, underscore the importance of quality in the company's products. The percentage of mean for quality, availability, and performance obtained were 96.3906, 60.4938, and 27.6188 respectively. This once again showed that quality of products is the greatest OEE factor that pharmaceutical companies must take seriously in order to reduce the six big losses in their manufacturing processes. Response Surface Method (RSM), with the application of Design Expert software with Box-Behnken as the design type was used to model, analyze, and optimize the Overall Equipment Effectiveness (OEE) using availability, quality, and performance as the input parameters. The analysis of both the actual and coded values, which is the main contribution of the study showed that quality has the greatest value followed by availability and performance. Also, OEE must be set at 10.3 and 629.5 for both the lower and upper limits respectively, in order to effectively reduce downtime, setup cost, the inherent wastes, as well as the six big losses.

1. Introduction

The pharmaceutical manufacturing industry has experienced drastic changes in production processes, supplies, management approaches, products, technological processes, and high customer demand for their products. This is because the contemporary changing environment has become highly competitive, and the manufacturing firms are finding it very difficult to handle competitions and consumers' expectations. To meet customers' expectations, there is need for effective working condition for most of the equipment, in order to achieve effective deliveries.

Many pharmaceutical companies are realizing that important production strategies hinges on equipment maintenance and reliability, which can influence the organization's competitive advantage. More so, when the maintenance processes can be streamlined to reduce or possibly

eliminate waste, and produce breakthrough performance in areas valued by customers.

Hence, the need for the adoption of Total Productive Maintenance (TPM) strategy, which is an important improvement process that emphasizes on equipment maintenance approach. Its positive impact has made many organizations to embrace it in order to enhance organizations' responsiveness in satisfying the customers' expected needs.

In TPM, the performance of a productive system is measured with a core quantitative metric known as Overall Equipment Effectiveness (OEE), which is one of the effective ways of analyzing the performance of one or more machines in a manufacturing organization. It comprises of performance rate, availability, and quality rate, which are measures of equipment losses.

^{*} Corresponding author.

^{**} Corresponding author.

E-mail addresses: cc.okpala@unizik.edu.ng (O.C. Chikwendu), ce.mgbemena@unizik.edu.ng (M.C. Edith).

The implementation of OEE strategy in manufacturing firms will enhance products' quality, reduce equipment break down, idle time, accident rates, and excess inventory, as well as scraps and defects.

This study is aimed at optimizing the OEE factors in a selected pharmaceutical company, by identifying and reducing losses, while also focusing on the fundamental causes of losses. A well-conceived TPM implementation program will not only bring appreciable improvement in other areas but will also lead to enhanced efficiency and equipment improvement, thereby enhancing the manufacturing company's profitability.

2. Literature review

2.1. Overall equipment effectiveness

Rouse (2017), defined OEE as “a measure of production operations performance and productivity, which is expressed as a percentage,” and observed that it “indicates the degree to which a manufacturing process is truly productive and serves as a general and inclusive measurement of how well a company's manufacturing operations are performing.” Also, Okpala et al. (2018), explained that OEE is an effective way of analyzing equipment performance, and also takes into account the major six big losses. They noted that it is a function of quality, performance rate and availability, which actually measures equipment losses.

However, Adolph et al. (2016), observed that OEE is a common approach for the measurement of production equipment efficiency, and originated in the frame of lean management with the introduction of Total Productive Maintenance. In TPM, the performance of a productive system is measured using a core quantitative metric called OEE. According to Ravishankar et al. (1992), OEE methodology incorporates metrics from all equipment manufacturing guidelines into a measuring system that helps manufacturing and operation teams to improve equipment performance, thereby reducing the cost of maintenance.

OEE can improve machine performance by identifying relevant performance opportunities. It's metric, which is the ratio of actual output of equipment to its greatest theoretical output, measures and also enhances the reliability of machine, products' quality, and changeovers' improvements Okpala and Anozie (2018).

As depicted in Figure 1, the six big losses of TPM are classified into six major categories namely: breakdown losses, setup and adjustment losses, defect and rework losses, start-up losses, speed losses, and idling and minor stoppage losses.

According to Dal et al. (2000), based on the six major losses, OEE can be measured by obtaining the product of performance efficiency of the process, the availability of equipment, and rate of quality products.

$$OEE = \text{Availability} \times \text{Performance efficiency} \times \text{Quality Rate} \tag{1}$$

where:

$$\text{Availability} = \frac{\text{Loading time} - \text{Down time}}{\text{Loading time}} \times 100 \tag{2}$$

Loading time is the available time planned per day or month for production operations, while downtime refers to the total time of production during which the integrated system is not operating due to equipment failures or setup/adjustment requirement.

$$\text{Performance efficiency} = \frac{\text{processed amount} \times \text{cycle time}}{\text{operating time}} \times 100 \tag{3}$$

Processed amount refers to the number of products processed in a day or month and operating time is the difference between loading time and downtime.

$$\text{Quality Rate} = \frac{\text{processed amount} - \text{defect amount}}{\text{processed amount}} \times 100 \tag{4}$$

Also, the Defect amount is the number of products rejected due to the inability of the product to meet up to production design, and therefore requires to be re-worked or may be regarded as scrap.

The world class OEE serves as a benchmark to evaluate the maintenance performance for the manufacturing organization, and to also improve the maintenance policy and effect the continuous improvement in the manufacturing systems. As depicted in Table 1, the world class goals for OEE, Availability, Performance rate, and Quality rate has 85, greater than 90%, greater than 95%, and greater than 99% respectively. If the calculated OEE is equal to world class OEE, it is interpreted that the manufacturing organization is in good condition, but if the OEE is less, then it means that there is a required urgent improvement of maintenance policies and strategies; otherwise it will be difficult for the manufacturing organization to sustain it.

2.1.1. The six major losses

1. **Equipment Failure** – This is a random failure that is caused by the breakdown of machines or equipment. According to Advice-Manufacturing (2019), equipment failure typically “occur when an

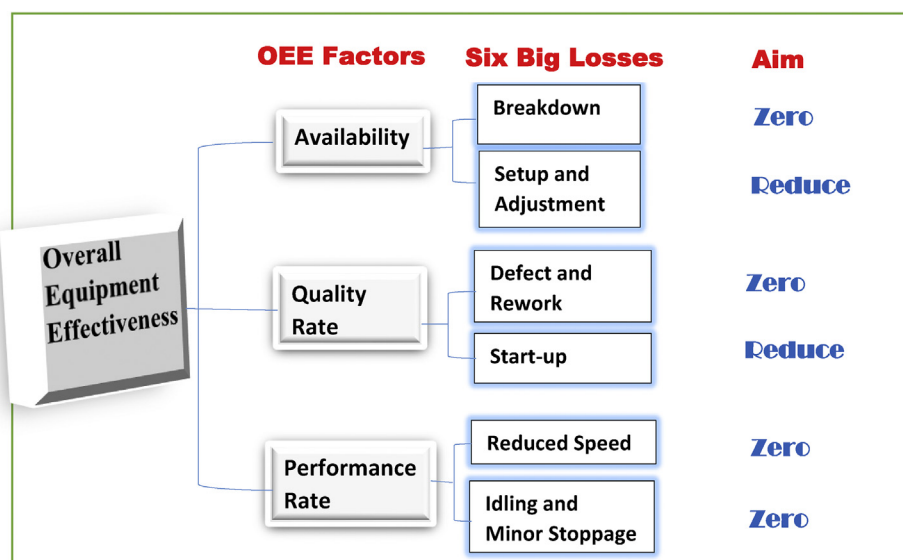


Figure 1. A model of overall equipment effectiveness.

Table 1. World class goals for OEE. Source: Jain et al. (2013).

OEE Factors	WORLD CLASS RATE (%)
Availability	>90
Performance Rate	>95
Quality Rate	>99
OEE	85

unplanned activity halts production, such as something breaking, equipment failing, or emergency maintenance”.

- 2. Set-up and Adjustment** – This is the loss of production time as a result of equipment adjustments. The application of one of the tools of TPM – Single Minute Exchange of Dies (SMED) leads to the reduction of high set-up time. According to [Ihuele and Okpala \(2014\)](#), the application of “SMED enables manufacturing companies to be more competitive by achieving the following: a decrease in lot size production, setup time reduction, decrease in planning and scheduling overhead, waste elimination, and more efficient utilization of material resources, thereby leading to the production of high quality products that meets the customer’s requirements.”
- 3. Idling and minor stoppages** – [Trout \(2018\)](#), explained that idling and minor stoppages are when equipment stops for a short period of time. He pointed out that it can be caused by jams, flow obstructions, wrong settings, as well as cleaning.
- 4. Reduced speed** – Also known as slow cycles, [Vijayakumar and Gajendran \(2014\)](#), explained that reduced speed is the difference between a machine design speed and actual speed of operation. Unfavorable environmental conditions, and inadequate equipment maintenance are some of the causes of reduced speed.
- 5. Defects and Rework** – These are losses that are incurred as a result of failing of machines and equipment to manufacture quality products of established standards. [Wudhikam \(2013\)](#), listed the following as the examples of defect and rework losses: “volume and time losses due to defect and rework, financial losses due to product downgrading, and time losses required to repair defective products to turn them into finished products”.
- 6. Reduced yield** – [Sakti et al. \(2019\)](#), defined reduced yield as “losses incurred during the time needed by a machine to produce new products with the expected product quality.” They noted that they are caused by unstable operating conditions, and incorrect equipment handling and installation.

3. Methods

3.1. The case study company

The study was carried out in Gauze Pharmaceutical and Laboratory Limited (GPLL), located at Enu-Ifite village, near government house Awka - Anambra State. The company produces syrups and tablets for human consumption. GPLL was established in the year 1992 but did not commence production until the year 2000. This delay was not due to

Table 2. 2016 to 2018 OEE Factors prior to the implementation of TPM.

Months	Availability (%)	Performance (%)	Quality (%)	OEE (%)
Jan. 2016	47.9	30.4	96.6	14.1
Feb. 2016	52.1	27.2	96.6	13.7
Mar. 2016	56.3	25.2	96.2	13.6
April 2016	60.4	26.7	95.6	15.4
May 2016	64.6	22.6	96.1	14.0
June 2016	62.5	22.0	96.0	13.2
July 2016	60.4	29.9	94.6	17.1
Aug. 2016	62.5	31.7	94.3	18.7
Sept. 2016	66.8	22.5	93.8	14.1
Oct. 2016	68.8	24.1	95.1	15.8
Nov. 2016	66.7	24.4	93.8	15.3
Dec. 2016	64.6	21.5	95.0	13.2
Jan. 2017	42.7	35.3	98.3	14.8
Feb. 2017	43.8	34.6	96.0	14.5
Mar. 2017	58.3	41.4	98.9	29.5
April 2017	31.3	33.4	98.9	10.3
May 2017	58.3	27.8	98.9	16.0
Jun. 2017	54.2	30.8	97.7	16.3
July 2017	54.2	35.4	98.2	18.8
Aug. 2017	62.5	33.3	98.7	20.5
Sep. 2017	72.9	27.4	98.3	19.6
Oct. 2017	65.0	33.3	98.9	21.2
Nov. 2017	65.6	34.3	98.5	22.2
Dec. 2017	66.3	23.9	96.8	15.3
Jan. 2018	58.3	28.7	94.0	15.7
Feb. 2018	66.7	21.3	94.4	13.4
Mar. 2018	72.9	21.7	95.8	15.2
April 2018	66.7	23.1	96.3	14.8
May 2018	62.5	24.7	94.9	14.6
Jun. 2018	64.6	21.5	95.0	13.2
July 2018	72.9	21.7	94.5	14.9
Aug. 2018	62.5	22.0	97.8	13.7

inactivity but because it took time for the company to develop its products and also tested them to confirm their quality. In the year 2000, the company commenced the production of eight (8) products after receiving approval from National Agency for Food and Drug Administration and Control (NAFDAC), and the Pharmacists Council of Nigeria (PCN). The firm’s production sequence is illustrated in [Figure 2](#).

3.2. Data collection and analysis

Two years and eight months’ data of the compression machine operation history was collected prior to TPM implementation, to ascertain the OEE baseline value before the TPM implementation. The main criterion for the identification and selection of the compression machine was because of its incessant failures and ability to enhance throughput

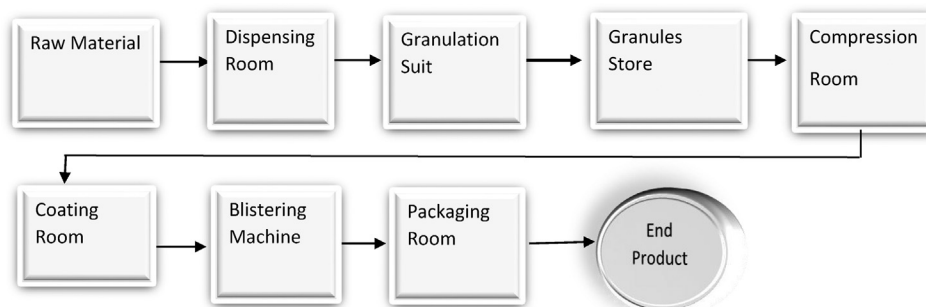


Figure 2. Illustration of sequence of tablet production in GPLL.

Table 3. The OEE factors after the implementation of TPM.

Sept–march (2018–2019)	Availability (%)	Performance (%)	Quality (%)	OEE (%)
Sept	72.9	35.2	98.0	25.4
Oct	75.0	35.2	99.5	26.3
Nov	77.1	40.5	99.6	28.7
Dec	79.2	43.9	99.7	34.7
Jan	81.3	45.5	99.6	36.8
Feb	83.3	45.8	99.7	38.0
Average (%)	$\sum + 78.1$	$\sum + 40.0$	$\sum + 99.4$	$\sum + 31.7$

Table 4. Descriptive statistics analysis.

	N	Minimum	Maximum	Mean	Std. Deviation
Availability (%)	32	31.30	72.90	60.4938	9.20161
Performance (%)	32	21.30	41.40	27.6188	5.42862
Quality (%)	32	93.80	98.90	96.3906	1.73119
Overall Equipment Effectiveness (%)	32	10.30	29.50	16.0219	3.58354
Valid N (listwise)	32				

when optimality is achieved. The Overall Equipment Effectiveness measurement metric was utilized to evaluate the equipment effectiveness of the compression machine, before the baseline study was conducted with six months data.

TPM lessons which include the applications and expected benefits were organized for the company’s staff when the manufacturing strategy was introduced, after which readings were taken to ascertain the improvement level. At first, before the TPM implementation, 5-whys approach was used to identify the potential causes of machine failures, after which the operators embarked on routine maintenance tasks at the commencement of every production day. The maintenance activities which were able to reduce some of the causes of breakdowns, also enhanced the rates of Overall Equipment Effectiveness, as depicted in Table 2.

The three OEE rates were determined individually, with the OEE calculated as the product of the three rates (Availability, Performance, and Quality).

4. Analysis of results

The data obtained were analyzed to interpret the OEE indicators using Eqs. (1), (2), (3), and (4), and are reported in Table 2, which shows the OEE values before TPM implementation, and also in Table 3 which depicts the OEE results after the implementation of TPM.

Table 5. Pearson correlations.

		Availability (%)	Performance (%)	Quality (%)	Overall Equipment Effectiveness (%)
Availability (%)	Pearson Correlation	1	-.572**	-.367*	.214
	Sig. (2-tailed)		.001	.039	.241
	N	32	32	32	32
Performance (%)	Pearson Correlation	-.572**	1	.606**	.651**
	Sig. (2-tailed)	.001		.000	.000
	N	32	32	32	32
Quality (%)	Pearson Correlation	-.367*	.606**	1	.430*
	Sig. (2-tailed)	.039	.000		.014
	N	32	32	32	32
Overall Equipment Effectiveness (%)	Pearson Correlation	.214	.651**	.430*	1
	Sig. (2-tailed)	.241	.000	.014	
	N	32	32	32	32

Although there are remarkable improvements in the company's OEE factors after the TPM implementation, however, there are still room for enhanced efficiency, hence the need for optimization.

The application of Minitab 16.0 software yielded the following results:

The descriptive statistics as shown in Table 4 reveals the statistical evaluation of the parameters in the system. It shows the values of mean, maximum, minimum and standard deviation in the data, with quality having the highest values.

In Table 5, Pearson correlation shows the level of significance the parameters are to each other. From the analysis, it shows that performance and quality are significant in predicting the Overall Equipment Effectiveness, unlike Availability that is not significant.

Table 6 shows one-sample test, which is a statistical tool used to express the statistical evaluation of the data in order to understand what the data portrays. It also reveals the significance of the univariate parameters in the system and develops the confidence interval of the mean differences. Here, the table shows that Quality has the highest value of mean difference and upper and lower Confidence Interval of the Difference (CIoD), followed by Availability and Performance.

As shown in Table 7, T-Test is a statistical tool used to express the statistical evaluation of the data, to ensure the proper understanding of what the data portrays.

The main effects plots depicted in Figures 3a, 3b, and 3c show the effects of Availability, Quality, and Performance respectively to the response.

As shown in the interactions plots Figures 4a, 4b, and 4c, the input factors have good interaction with each other. It also shows that the input factors will be significant to each other due to the good interactions in the plot.

4.1. Response surface method using Design Expert (10.0) software

The Design Expert (10.0) software is applied to model, analyze and optimize the OEE using availability, quality and performance as the input parameters.

Table 6. One-sample test.

	Test Value = 0					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Availability (%)	37.190	31	.000	60.49375	57.1762	63.8113
Performance (%)	28.780	31	.000	27.61875	25.6615	29.5760
Quality (%)	314.968	31	.000	96.39063	95.7665	97.0148
Overall Equipment Effectiveness (%)	25.292	31	.000	16.02188	14.7299	17.3139

Table 7. T-test (one-sample statistics).

	N	Mean	Std. Deviation	Std. Error Mean
Availability (%)	32	60.4938	9.20161	1.62663
Performance (%)	32	27.6188	5.42862	.95965
Quality (%)	32	96.3906	1.73119	.30603
Overall Equipment Effectiveness (%)	32	16.0219	3.58354	.63349

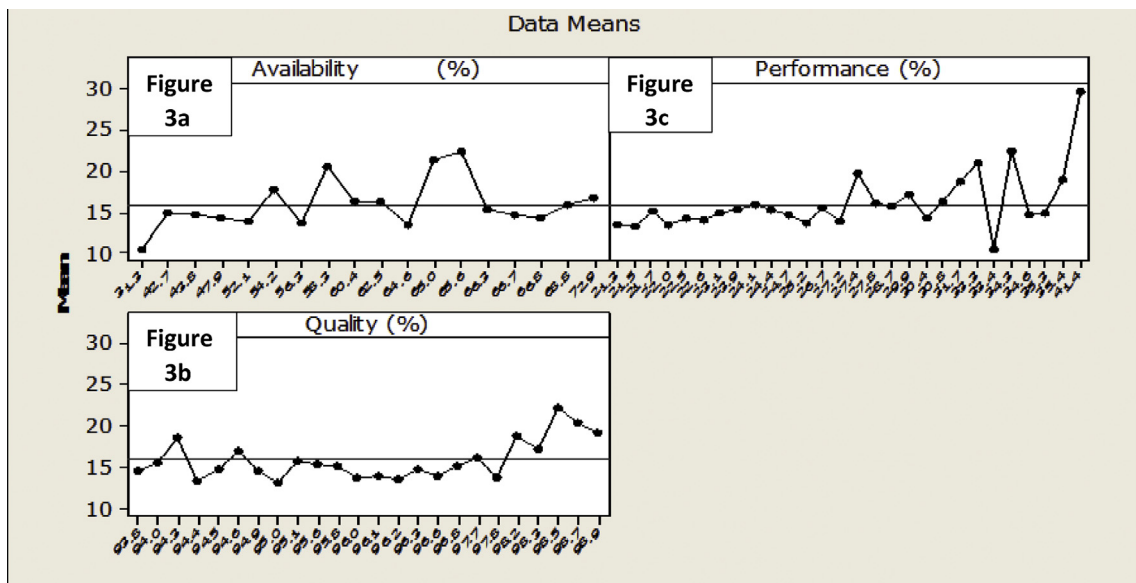


Figure 3. a: Main Effects plot for Availability; b: Main Effects plot for Quality; c: Main Effects plot for Performance.

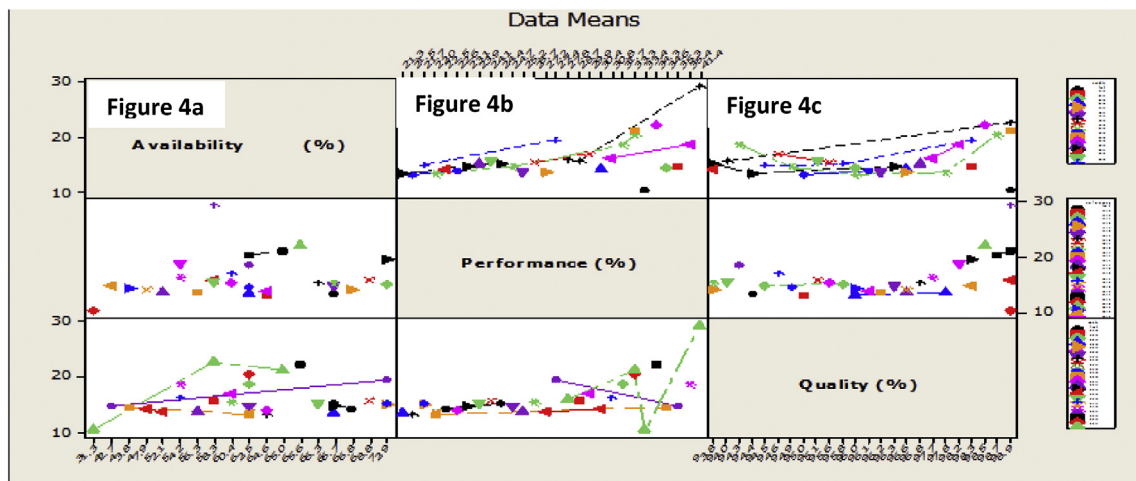


Figure 4. a: Interaction plot for Availability and others; b: Interaction plot for Performance and others; c: Interaction plot for Quality and others.

Table 8. Statistical analysis of the input parameters.

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Availability (%)		Numeric	Continuous	31.3	72.9	-1.000 = 31.3	1.000 = 72.9	60.4938	9.20161
B	Performance (%)		Numeric	Continuous	21.3	41.4	-1.000 = 21.2	1.000 = 41.4	27.6188	5.42862
C	Quality (%)		Numeric	Continuous	93.8	98.9	-1.000 = 93.8	1.000 = 98.8	96.3906	1.73119

Table 9. The summary of the selected model of the OEE.

Response	1	Overall Equipment Effectiveness	Transform:	None	
Summary (detailed tables shown)					
Source	Sequential	Lack of Fit	Adjusted	Predicted	
	p-value	p-value	R-Squared	R-Squared	
Linear	<0.0001		0.9313	0.8888	
2FI	0.0246		0.9467	0.8798	
Quadratic	<0.0001		0.9809	0.8891	Suggested
Cubic	<0.0001		0.9984	0.8578	Suggested
Quartic			1.0000		Aliased

Table 10. Sequential model sum of squares.

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	8214.42	1	8214.42			
Linear vs Mean	373.39	3	124.46	141.04	<0.0001	
2FI vs Linear	7.61	3	2.54	3.71	0.0246	
Quadratic vs 2FI	11.69	3	3.90	15.88	<0.0001	Suggested
Cubic vs Quadratic	5.16	10	0.52	25.70	<0.0001	Suggested
Quartic vs Cubic	0.24	11	0.022			Aliased
Residual	0.000	1	0.000			
Total	8612.51	32	269.14			

Final Equation in Terms of Coded Factors:

Overall Equipment Effectiveness	=
+15.76	
+6.10	* A
+5.34	*B
+0.17	*C
+2.06	* AB
-1.67	* AC
-0.92	* BC
-2.01	* A ²
+1.77	*B ²
-0.40	*C ²
+0.92	* ABC
+1.18	* A ² B
+41	* A ² C
+4.44	* AB ²
+1.25	* AC ²
+0.20	*B ² C
-0.022	* BC ²
+0.80	* A ³
+3.16	*B ³
+0.33	*C ³

Table 8 shows the input parameters, which reveals the input factor levels, means and standard deviations in the system.

Table 9 suggested the model to be used for best optimal solutions in the system. From the model the quadratic and the cubic was suggested for the model.

As shown in Table 10, sequential model sum of squares selects the highest order polynomial where the additional terms are significant and the model is not aliased. However, the system suggests the model to be used in the system for best optimal solutions.

Ignoring the insignificant values, the final equation of OEE in terms of actual factors becomes:

$$OEE = 15.76 + 6.10A + 5.34B + 0.17C + 2.06AB - 1.67AC - 0.92BC$$

where A, B, and C are Availability, Performance, and Quality respectively.

The equation in terms of coded factors is applied for the predictions of response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

The contour plot is used to reveal the influence of the input parameters to the output parameter. Figure 5 shows that the increase in Availability and Performance variables will increase the Overall Equipment Effectiveness.

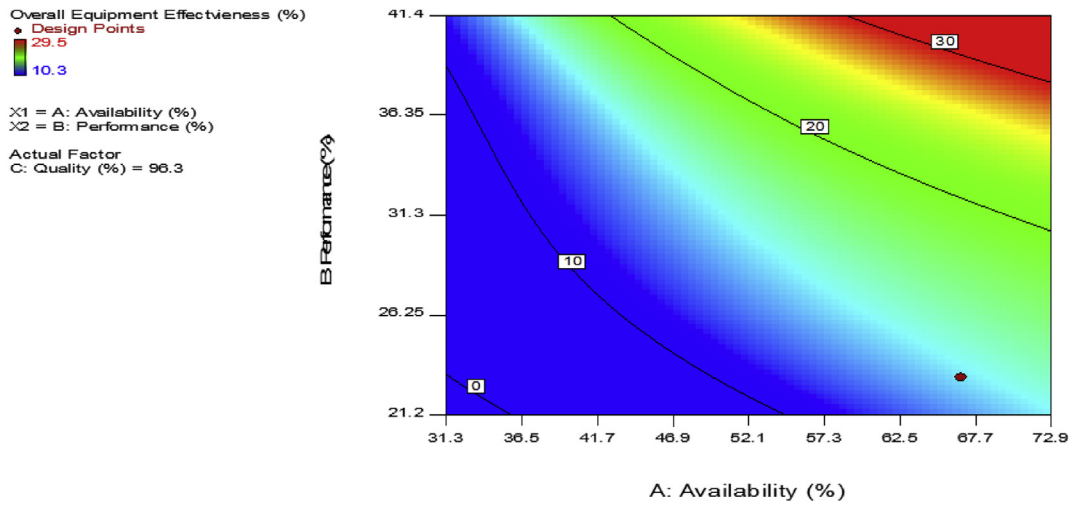


Figure 5. Contour plot of performance vs Availability.

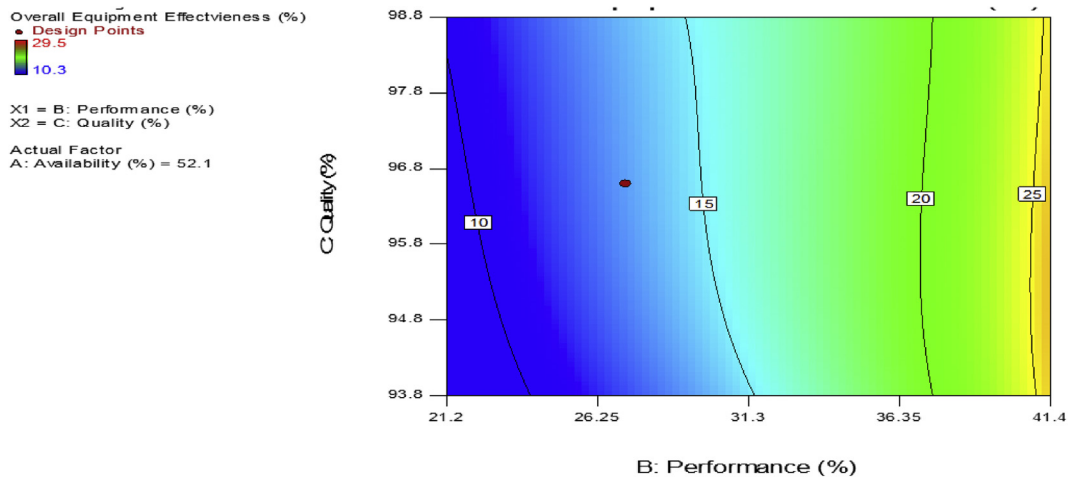


Figure 6. Contour plot of Quality vs Performance.

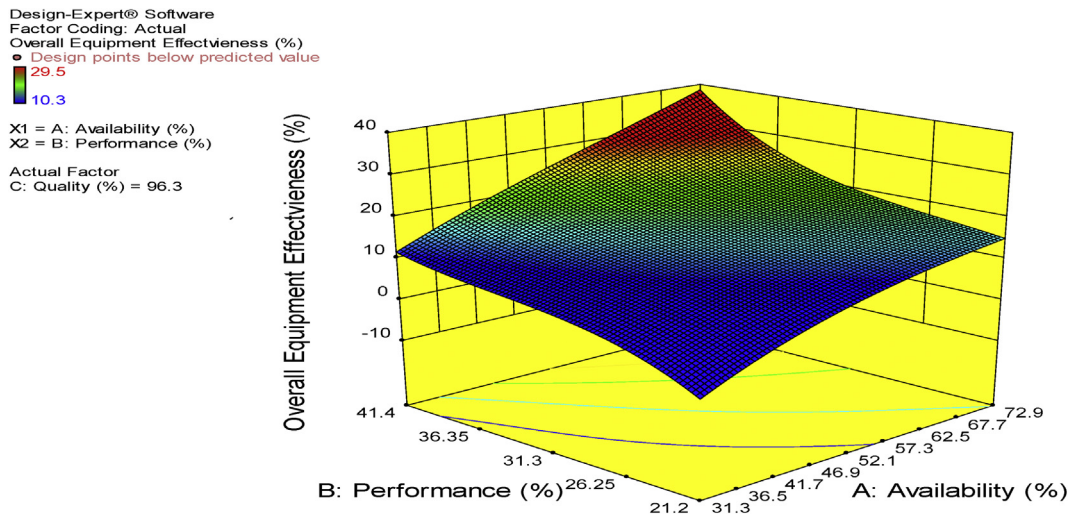


Figure 7. Response Surface plot of Performance vs Availability.

Table 11. Criteria for optimal solutions in the system constraints.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Availability (%)	is in range	31.3	72.9	1	1	3
B:Performance (%)	is in range	21.2	41.4	1	1	3
C:Quality (%)	is in range	93.8	98.8	1	1	3
Overall Equipment Effectiveness	Maximize	10.3	29.5	1	1	3

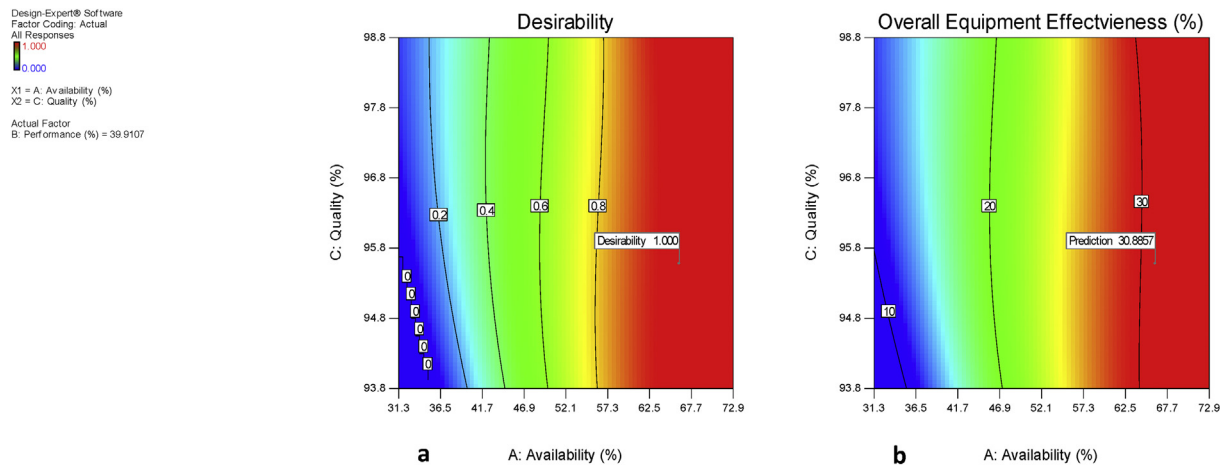


Figure 8. a: Desirability Contour plot of Quality vs Availability; b: Overall Equipment Effectiveness Contour plot of Quality vs Availability.

The contour plot in Figure 6 is used to reveal the influence of the input parameters to the output parameter, it shows that the increase in performance will increase the overall equipment effectiveness, while the increase or decrease in quality variables will keep the overall equipment effectiveness at low level.

Figure 7 shows that the increase in Availability and Performance variables will increase the overall equipment effectiveness.

Table 11 shows the criteria for the optimization solution of the system. It shows the limits of the input parameters and output parameters to optimize the best solution.

The desirability and Overall Equipment Effectiveness contour plots in Figures 8a and 8b respectively show that the desirability of 100% occurs at 30.886% of the OEE, with input factors of Availability and Quality parameters of the independent variables.

The data collected in Table 2, and the result of the data in Table 3, were calculated using availability, performance, and quality formulae to obtain the Overall Equipment Effectiveness factors.

The response surface method also revealed that both the minimum and coded values show that quality has the greatest value followed by availability and performance. Also, the maximum values for all the three OEE factors validates the results of Minitab 16.0 as the percentage values of quality, availability, and performance are 98.9, 72.9, and 41.4 respectively.

In Table 5, Pearson correlation shows the level of significance the parameters are to each other. From the analysis, it shows that performance and quality are significant in predicting the overall equipment effectiveness, while availability is not significant in predicting the Overall Equipment Effectiveness. The highest value of 98.90 and 96.39 in the descriptive statistics for the maximum and mean respectively underscore the importance of quality in products.

As shown in Table 4, the percentage of mean for quality, availability, and performance are 96.3906, 60.4938, and 27.6188 respectively, this once again shows that the quality of products is the greatest OEE factor that pharmaceutical companies must take seriously in order to reduce the six big losses, and the other wastes that are inherent in their manufacturing processes.

5. Conclusion

The research concludes that the implementation of TPM in organizations as performance improvement tool has various benefits and challenges. An effective application of Total Productive Maintenance program focuses on addressing these challenges, thus resulting in optimized equipment performance in the company. TPM concepts and philosophy can be effectively implemented to realize fundamental improvements in the manufacturing performance in any pharmaceutical firm or any other company, thereby leading organizations successfully in the highly competitive drug market.

The results of the study that OEE improves equipment performance confirmed the findings of Ravishankar et al. (1992), and Okpala et al. (2018), as it is an effective way of analyzing equipment performance, and also takes into account the six big losses. For the optimization of the pharmaceutical company's Overall Equipment Effectiveness, the percentage lower limits of the OEE factors of quality, availability, and performance must be set at 93.8, 31.3, and 21.2 respectively, while the upper limits must be set at 98.8, 72.9, and 41.4 respectively. Also, OEE must be set at 10.3 and 29.5 for both the lower and upper limits respectively.

The application of the model equation terms of coded factors in any pharmaceutical company will lead to reduction of the following six big losses: equipment losses, setup and adjustment, idling and minor stoppages, reduced machine speed, defective products, and reduced yield.

The major limitation of the research which stalled the initial commencement of the study was caused by the incessant power outages which was caused by the irregular power supply in Nigeria. However, remarkable improvements were recorded when the management of the company procured an alternative source of energy with the installation of a standby generating set.

Although the firm has made a lot of progress since the TPM introduction, however, the wastes of excess inventory, defects, and overproduction are still rampant in the establishment. Further studies should therefore incorporate the strategies of Lean Production System

(LPS) with TPM. This the authors believe will enable manufacturers to shift emphasis from meeting the customers' requirements to exceeding their expectations.

Declarations

Author contribution statement

Okpala Charles Chikwendu: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Anozie Stephen Chima: Analyzed and interpreted the data.

Mgbemena Chika Edith: Performed the experiments.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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