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Optimizing and Analyzing Overall Equipment Effectiveness (OEE) through Design of Experiment (DOE) of a local Cement Industry

MUHAMMAD ALAM ZAIB KHAN
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

MUHAMMAD ALI KAMRAN
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

YAHYA RAHMAN
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

SOBAN ALI SHAH
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

SHEHZAD KHAN
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

NAVEED AHMAD
Department of Mechanical engineering,
University of Engineering and Technology, Peshawar, KP, Pakistan.

Abstract

This paper presents an analysis of Overall equipment effectiveness (OEE) of a factory; calculating the actual manufacturing time of specified machine: Kiln, Crusher, Cement mill, and Raw press. An attempt has been done to measure existing overall equipment effectiveness of machinery processes working at desired conditions and ensure; measured the availability, performance rate and quality rate of existing system. For purpose to utilize the existing machinery at their productive capacity to achieve world class standard of OEE. The full factorial of availability, performance rate and quality rate resulted into optimized result, however, critical factor are observed. Significance of each factor is indicated by P-value and F-values in the given analysis. Finally, optimized values of OEE, Kiln 97.56%, Crusher 35.57%, Cement mill 96.1% and Raw press 90.58%. Optimized values create a presentation model in form simulated result output is useful information to industry.

Keywords: *OEE, Design Expert, DOE.*

Introduction

Industry plays a vital role in the economic development of a certain country, resulting in shape of productive services. For such anticipation the effectiveness and efficiency paly important role, to become a

on organization more productive (Relkar & Nandurkar, 2012). For the prosperity and better future of Pakistan, the industries of country need a practical and efficient technique which are helpful for the purpose of experimentation- which is regular activity of engineers practice for observation, analysis of experiments and daily life process in industries. And to develop practical techniques of experiment for optimization of an industry, anticipate the maximum output, utilizing the existing resources. But unfortunately, no such trail is practiced in Pakistan for the productive outcome in industry; to exploit their existing machinery for enhanced production. For this purpose, OEE measured key parameters in both productivity and efficiency, in addition to this, it is yield with the help of very simple and minute calculation and can be done by skilled worker, which doesn't need any expert. Moreover, OEE compensates how effectively utilizes a manufacturing process and allows us to identify potential equipment, critical equipment, track losses, and window of opportunity. In a manufacturing perspective, the desirable productivity, cost of product, inventory, quality rate and product delivery are all rely on the proficiency functioning of the company facilitating efforts. The main objective of Overall Equipment Effectiveness (OEE) measurement and analysis, to decline the equipment losses to zero, has been recognized as essential for organizations. (Gandhinathan & Badiger, 2008). The role of the OEE is beyond just monitoring and control (Dal et al., 2000) and takes account of in certain things such as process improvement initiatives, preventing suboptimization of each individual machines or production lines, it's also provides a systematic method for establishing production targets and integrates practical management tools and techniques to make it possible in depicting a balanced view of process availability, performance rate and quality rate. Jonsson and Lesshammar (1999) presented their case studies how OEE is being helpful in industries, and also have reported that OEE forms an important part of an overall system of measurement (Hedman, et al., 2016).

$$\text{Availability}(\%) = \frac{\text{Operating time}}{\text{Net available time}} \times 100$$

$$performance\% = \frac{Processed\ amount \times \text{Theoretical cycle time}}{Operating\ time} \times 100$$

$$Quality(\%) = \frac{\text{Good parts}}{\text{Total parts}} \times 100$$

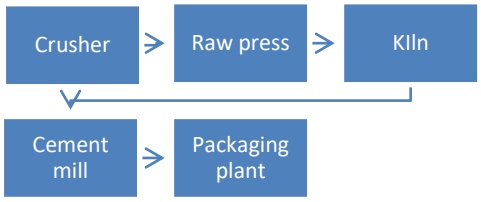


Figure 1: Model of production line

The OEE calculation is quite simple and general to be applied to any manufacturing organization (Pomorski, 2004). Even though OEE is developed out of TPM, which doesn't need for an organization to implement TPM for gaining its benefits. OEE does not evaluate a specific rational reason why a machine not running most effectively as possible, however, it does help indicating the possibility for equipment improvement (da Costa & de Lima , n.d.). The work notes of Godfrey (Godfrey, 2002) for the efficient execution of each piece of production equipment, assembly lines or the complete factory body depend on the three OEE factors (availability, performance efficiency and quality rate). Ideally, breakdowns can be vanished totally upon maintenance prevention (MP), or the exploiting maintenance-free design; this circumstances of mostly factory equipment, however, we are far from this ideal (Nakajima, 1984). And these losses are divided in six major categories that can affect the overall performance of equipment by Nakajima, below:

1. The timeframe losses and amount losses claimed by faulty goods are expected by equipment problems losses.
2. Losses in setup and adjustment can be described as the time loss that can result by breakdown and the faulty items that occurs if one particular item ends in production and the equipment is then adjusted to meet another item's required requirement.
3. Idling and small pause losses occur when a temporary malfunction disrupts the output or the system is idle.
4. Reduced speed losses include the difference between both the speed of the equipment setup and the function of the real speed equipment.
5. The initial stage of production, from system start to stabilization, is the occurrence of reduce yield losses.
6. The losses in quality influenced by the failure of manufacturing machinery were reworked and quality faults.

The first two losses are known as downtime losses; which anticipates availability of a machine. The next pair of losses determine the performance efficiency and lastly remaining losses are considered caused by defects in the products. OEE is calculated in these six term losses, and its function of availability, and performance rate and quality rate of the existing machine, production line or factory (Gandhinathan & Badiger, 2008). Mathematical forms are given below;

OEE: Measurement identifies problems

The goal was to quantify the efficiency of individual production equipment in a factory as a quantitative metric.; introduces new ways to measure undiscovered or irrelevant costs related to a piece of equipment (Relkar & Nandurkar, 2012). The research objective is exercising the machinery on standard OEE and to calculate the currently OEE values of machinery process, furthermore, to know which of OEE among availability, performance rate and quality rate is lacking behind from their standard values. It was needed to analyse all factors of OEE at the same time, to know OEE is normal and difference from standard OEE. Certainly, to identify the most influencing factor, on a machine. Also, to have benefits of OEE assertion of Critical machines are necessary to optimize the production. Which can be very fruitful for the operating industry on standard OEE. Addition to this, OEE identify bottlenecks and decisions in 'isolated' parts of the manufacturing process; which can be used to govern supply chain of overall effectiveness (Godfrey, 2002). OEE can be utilize as conceptual framework using Lean Six sigma's DMAIC for minimizing the Bottleneck process in Semiconductor Industry (Prasetyo & Veroya, 2020). OEE is metrics describing performance of equipment; rating for creating strategies for improvement of production processes, identity "bottlenecks", technical and includes organizational problems of certain company (Gola & Nieoczym , 2017).

Table 1: Actual cycle time of manufacturing equipment

Name of machines	Crusher	Raw press	Kiln	Cement mill	Packaging Plant
Actual cycle time	600 ton/hr	300 ton/hr	146 ton/hr	256 ton/hr	5 ton/hr (total 5 packer)

The main focus of our research was to bridge the gap between industries and DOE. In order to make way for a better nascent future of industries; conducted this research to utilize DOE and how they will be able to exploit this in their daily practices. Which will be helpful to achieve their niches (any industry) and how it can be possible and solve their real problems. Furthermore, DOE is one of the common methods for assessing user response to product development; it entails constructing the proper relationship between response and relevant variables, as well as drawing conclusions about user preferences with less experiments conducted (Lin, et al., 2017). Indeed, how to utilize the existing machinery of industry more efficiently and effectively. DOE presents best possible interaction among factors to relate relationship. Therefore, we prefer DOE which anticipates the worth result compensated by most effective analysis

without monthly long trails in industry. Addition to this, OEE is not simply calculated by traditional methods to make only changes in the noted vulnerable area but it was found the interaction between factors for the best possible outcome with the help of DOE. Moreover, significance of which factor more affects the OEE of a machine was illustrated by their dominant factors are shown in results. Finally, the contribution was not limited to optimized outcome utilizing low and high levels, not to compromise on traditional OEE calculation but clearly represents by statistical model in full factorial and significance is elaborated by ANOVA. Furthermore, the experiment was conducted on local Cement factory-there were three lines in factory- on line 2 for evaluating critical machinery; each line having the following four machinery (figure 1) and to ensure machinery is working at desired standard of OEE which is 85% (Stamatis, n.d.); this world class value OEE is obtained to be 85% comprising of Availability 90.0%, Performance 95% and Quality 99.9%.

Pre-experiment was conducted on the major categories of OEE for measuring manufacturing performance of factory (based on machine spices shown in table 1), the below figure 2 illustrates Nakajima model (Cheh, n.d.) of OEE and their time calculation of a running machine Kiln in the factory; the 37% OEE of machine is below the standard metrics of OEE, and main reason of this research conducting on the machinery of cement industry for optimization.

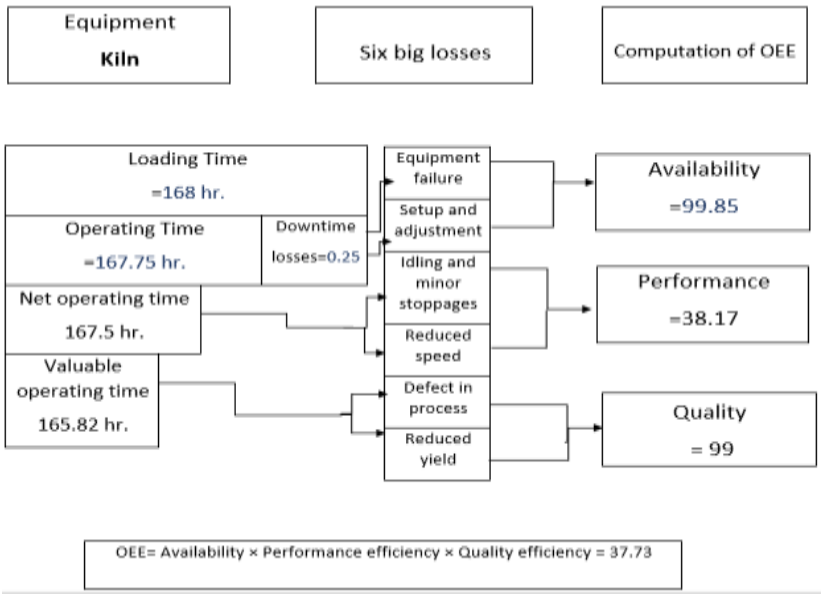


Figure 2: Overall equipment effectiveness and computation procedure

Research Methodology

Design of experiments (DOE) can be exploit to examine affects output of OEE and at what rate (Relkar & Nandurkar, 2012). DOE begins with determining the objectives of an experiment and selecting the response factors for the study. Chosen experimental designs increase up to maximum level the Information obtained from an experimental effort. (MONTGOMERY , n.d.).

The aim for exploiting this particular method was to accustomed this method in our industry because it was hardly used in our country. Moreover, DOE application is simpler, more practical and tackles problems in key processes which are dealt with every day. (Tanco, et al., 2007). The most influential applications of DOE in manufacturing processes are included: Improved yield and process reliability, increased profits and yield on investment, improved method ability, decreased process variance and thereby improved product

performance consistency, lower manufacturing costs, Reduced process engineering and building time, enhanced engineers' morale by progress in chronic-problem solving, improved understanding of the connection between main process inputs and outputs, and increasing economic profitability through lowering scrap, failure, remodel, and retest rates., etc (Antony, October 2003). Addition to this, based on the design of experiments, inverse regression and alternate planning techniques can be used (Taslim, et al., 2020).

Furthermore, DOE results predict the influencing factor in the result in relevant manner and analyze the interdependent factors, if they. (Weissman & Anderson, 2015). Analysis are shown through half-normal plots and analysis of variance (ANOVA); used Design of expert software for optimization. In this research Full Factorial design is used and changes the factors together, studied their individual affect and the interaction of factors which affect the response.

This study is carried out in local Cement industry, because OEE is not utilize in manufacturing factories manufacturing time of machines are calculated in order to check their present OEE encompass standard; the data of four machines were collected in four weeks for the purpose of OEE and calculated availability and performance (Annex 1) and quality is not issue for factory because rejection rate was very low, so quality rate found in between 97 to 99%. From which the Availability, Performance Rate and Quality Rate were calculated on excel sheet. The experiment was performed on Design Expert in 8 runs- 2^3 factorials- having 3 factors and at two levels; low and high level.

The detail results of each machine are discussed below.

Kiln

Full factorial design of Kiln

The full factorial design is carried out on three factors, which having eight runs, one replicates, one blocks and zero Center points. (Annex 2)

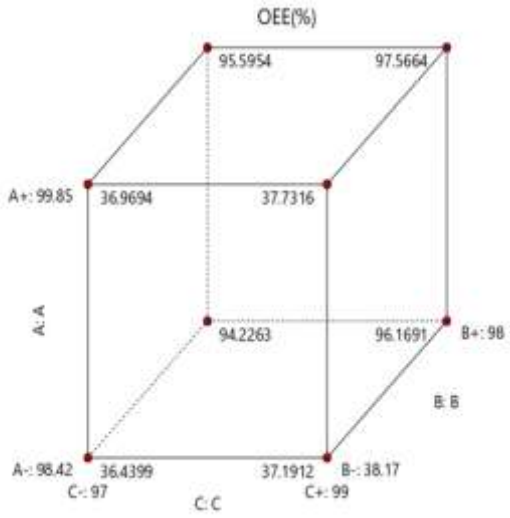


Figure 3: Cube plot of predicted response of OEE for kiln

As shown in the geometric cube figure 3, the factor A, B, and C shows their low "- "and high "+" level respectively (MONTGOMERY , n.d.), and the effect of change in each factor is demonstrated in cube, clearly visible their compensation in the OEE. The maximum OEE is resulted 97.56 from the high level of factor A, B, and C.

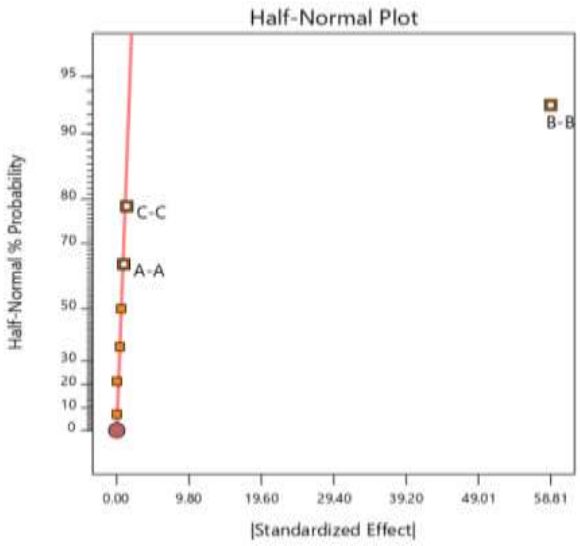


Figure 4: Half-normal plot of effects on OEE

The in the Half-Normal plot (figure 4) the points lying on the line are noise or normal process variation in our data, while the point in the right from the line are significant effect causing significant changes (Anderson & Withcomb, 2015), which is performance. The highest effect, performance rate (B) which have absolute value of 58.8, is plotted at 93.5 % probability, next availability (A) and quality (C) having 0.959 and 1.356 respectively, with 79% and 65% probability as well.

ANOVA for selected factorial model

Table 2: ANOVA response model of OEE for kiln

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6921.88	3	2307.29	8544.25	< 0.0001	significant
A-A	1.84	1	1.84	6.81	0.0594	
B-B	6916.36	1	6916.36	25612.31	< 0.0001	significant
C-C	3.68	1	3.68	13.64	0.0210	
Residual	1.08	4	0.2700			
Cor Total	6922.96	7				

The Model calculated F-value which is 8544.25 emphasizes the model is significant in table 3. P-values smaller than 0.0500 indicate that model terms are significant. In this case, both B, C and C are essential model names. Values over 0.1000 indicate that model parameters are not relevant. (Frost , n.d.)

$$OEE\ (\%) = +66.49 + 0.4795A + 29.40B + 0.6784C$$

In terms of coded variables, the equation can be used to make assumptions about the response of each factor to given levels. The high levels of the variables are coded by default as +1 and the low levels are coded as -1. Through comparing the component coefficients, the coded equation is useful for anticipating the relative influence of the variables. (Frost , n.d.). Moreover, the performance (B) is relative most impactful on OEE in Kiln.

$$OEE\ (\%) = -132.97 + 0.67A + 0.97B + 0.678C$$

The equation can be used in terms of individual variables to make assertions about the response of each factor to certain amounts.

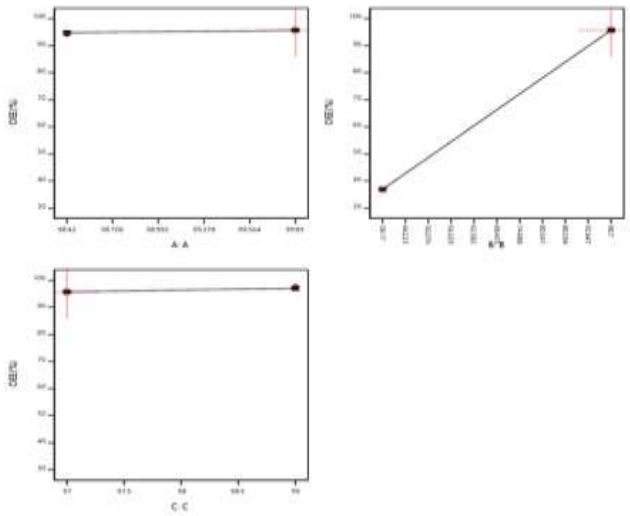


Figure 5: Main effects Availability (A), Performance rate (B) and Quality (C) on OEE

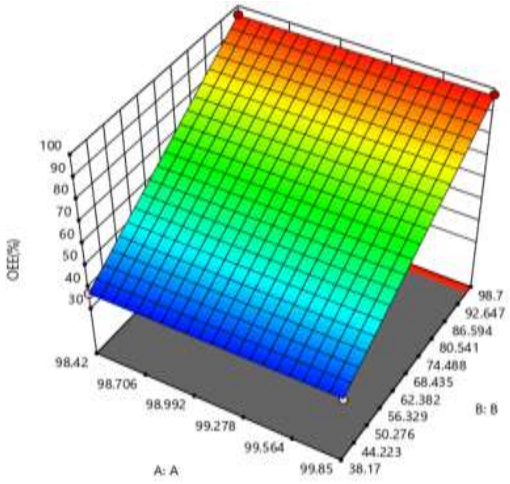


Figure 6: Interactions effect of Availability (A), Performance rate (B) and Quality (C) on OEE

Result

The main effects graph indicates the quality (C) and Availability (A) hardly effect OEE, while performance rate (B) positively affects the OEE of Kiln, ranging performance rate from 38.17 to 98.7, OEE is affected in between 36.44% to 97.56%. (Antony, October 2003). The plot of the interaction between performance vs quality at their both low-level and high-level spawning OEE from 36.43% to 97.56%.

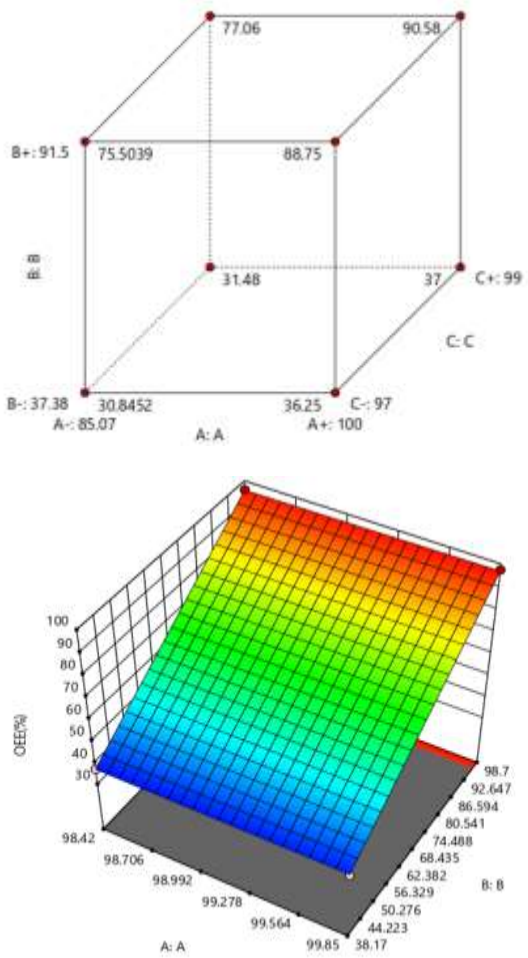


Figure 7: Cube plot of predicted response of OEE for Raw press

Raw press

Full factorial design of Raw press

The full factorial design is carried out on three factors, which having eight runs, one replicates, one blocks and zero Center points. (Annex 3)

As shown in the geometric cube, the factor A, B, and C shows their low "- "and high "+" level respectively, and the effect of change in each factor is demonstrated in cube, clearly visible their compensation in the OEE. The maximum OEE is resulted 90.58 from the high level of A, B, and C.

In the Half-Normal plot, the points lying on the line are noise or normal process variation in our data, while the points in the right from the line are significant effect causing significant changes, which are availability, and performance. The highest effect, performance rate (B) which have absolute value of 49.07, is plotted at 94% probability, next availability (A) and quality (C) having 9.42 and 1.19259 respectively, with 80% and 50% probability as well.

ANOVA for selected factorial model

Table 3: ANOVA response model of OEE for Raw press

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4998.00	3	1666.00	209.07	< 0.0001	significant
A-A	177.79	1	177.79	22.31	0.0091	significant
B-B	4817.37	1	4817.37	604.54	< 0.0001	significant
C-C	2.84	1	2.84	0.3570	0.5824	
Residual	31.87	4	7.97			
Cor Total	5029.88	7				

The Model calculated F-value in table 3 which is 209.07 emphasizes the model is significant. P-values smaller than 0.0500 indicate that model terms are significant. In this case, both A, and B are essential model concepts. Values over 0.1000 indicate that model parameters are not relevant.

$$OEE\ (\%) = 58.44 + 4.71A + 24.54B + 0.5963C$$

The equation in terms of coded factors can be exploited to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for anticipating the relative impact of the factors by comparing the factor coefficients. Here, the performance rate (B) has relative high impact.

$$OEE\ (\%) = -116.87 + 0.631A + 0.906B + 0.5962C$$

The equation can be used in terms of individual variables to make assertions about the response of each factor to certain amounts.

Result

The main effects graph indicates the quality (C) and Availability (A) hardly effect OEE, while performance rate (B) positively affects the OEE of Kiln, ranging performance rate from 38.17 to 98.7, OEE is affected in between 36.44% to 97.56%. (Antony, October 2003).

The plot of the interaction between performance vs quality at their both low-level and high-level spawning OEE from 36.43% to 97.56%.

Raw press

Full factorial design of Raw press

The full factorial design is carried out on three factors, which having eight runs, one replicates, one blocks and zero Center points.

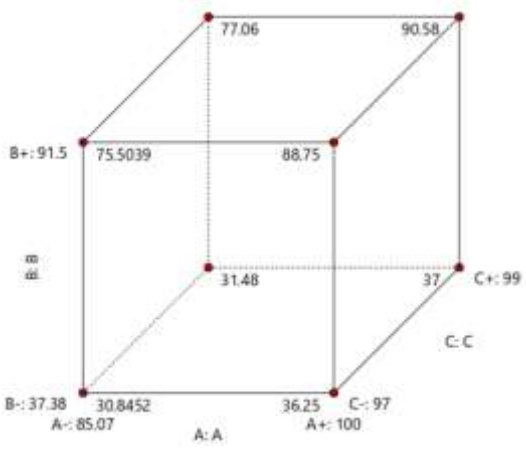


Figure 8: Cube plot of predicted response of OEE for Raw press

As shown in the geometric cube, the factor A, B, and C shows their low "- "and high "+" level respectively, and the effect of change in each factor is demonstrated in cube, clearly visible their compensation in the OEE. The maximum OEE is resulted 90.58 from the high level of A, B, and C.

In the Half-Normal plot, the points lying on the line are noise or normal process variation in our data, while the points in the right from the line are significant effect causing significant changes, which are availability, and performance. The highest effect, performance rate (B) which have absolute value of 49.07, is plotted at 94% probability, next availability (A) and quality (C) having 9.42 and 1.19259 respectively, with 80% and 50% probability as well.

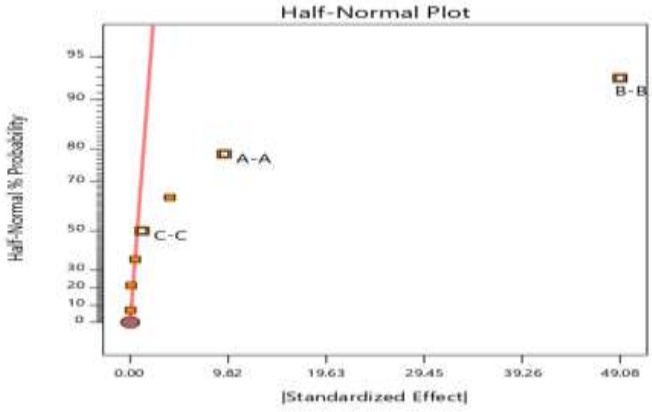


Figure 9: Half-normal plot of effects for OEE

ANOVA for selected factorial model

Table 4: ANOVA response model of OEE for Raw press

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4998.00	3	1666.00	209.07	< 0.0001	significant
A-A	177.79	1	177.79	22.31	0.0091	significant
B-B	4817.37	1	4817.37	604.54	< 0.0001	significant
C-C	2.84	1	2.84	0.3570	0.5824	
Residual	31.87	4	7.97			
Cor Total	5029.88	7				

The Model calculated F-value in table 3 which is 209.07 emphasizes the model is significant. P-values smaller than 0.0500 indicate that model terms are significant. In this case, both A, and B are essential model concepts. Values over 0.1000 indicate that model parameters are not relevant.

$$OEE\ (\%) = 58.44 + 4.71A + 24.54B + 0.5963C$$

The equation in terms of coded factors can be exploited to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for anticipating the relative impact of the factors by comparing the factor coefficients. Here, the performance rate (B) has relative high impact.

$$\text{OEE}\ (\%) = -116.87 + 0.631\text{A} + 0.906\text{B} + 0.5962\text{C}$$

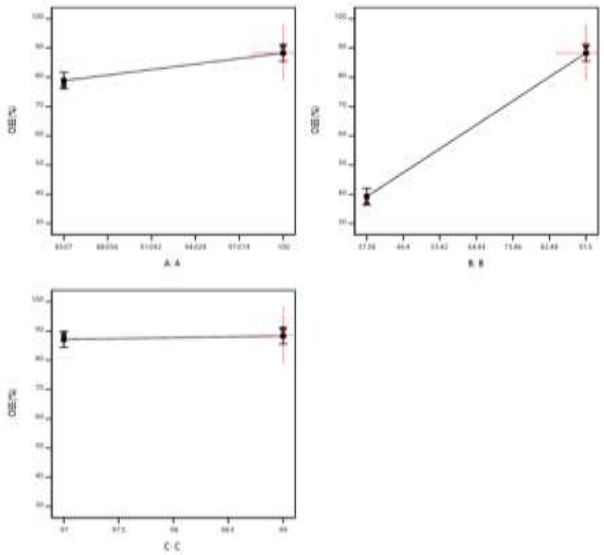


Figure 9

The equation can be used in terms of individual variables to make assertions about the response of each factor to certain amounts.

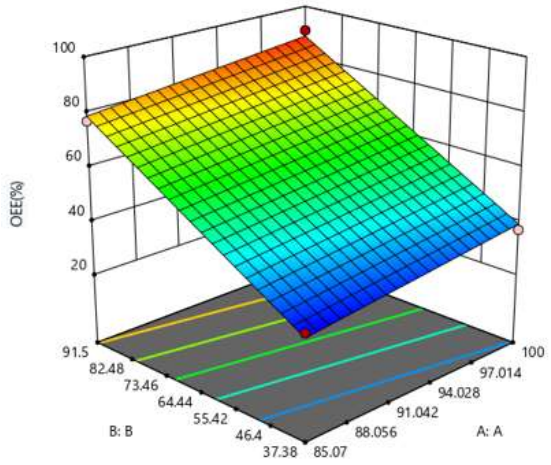
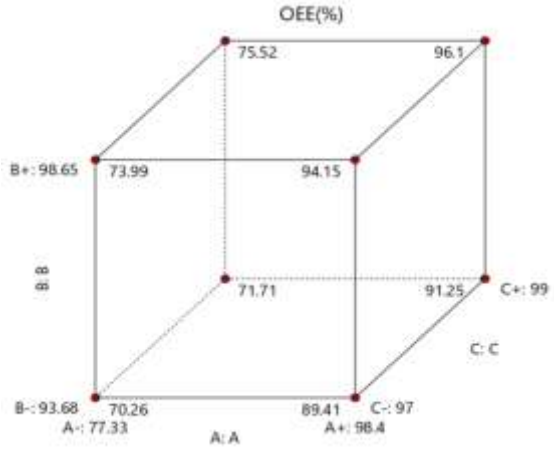


Figure 10: Interaction effects Availability (A), Performance rate (B) and Quality (C) on OEE

Results

The main effects graph indicates the quality (C) and Availability (A) hardly effect OEE, while performance rate (B) positively affects the OEE of Raw press, ranging performance rate from 37.38% to 91.5%, OEE is affected in between 30.84 to 90.585%.

Figure 11



The plot of the interaction between performance vs quality at their both low-level and high-level spawning OEE from 30.84% to 90.58%.

Cement mill

Full factorial design of Cement mill/ Ball mill

The full factorial design is carried out on three factors, which having eight runs, one replicates, one blocks and zero Center points. (Annex 4).

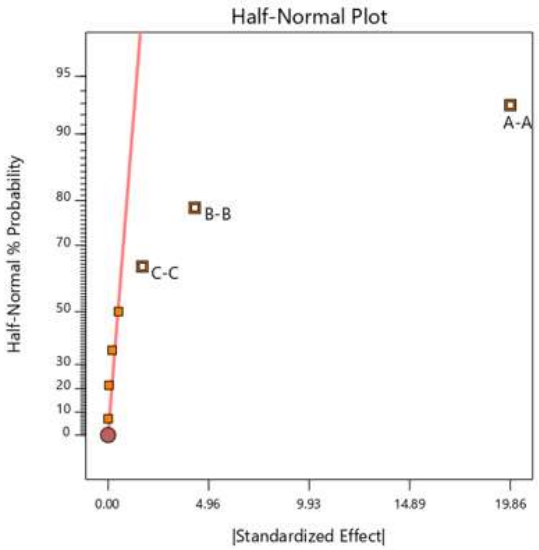


Figure 12

As shown in the geometric cube (figure 12), the factor A, B, and C shows their low "- "and high "+" level respectively, and the effect of change in each factor is demonstrated in cube, clearly visible their compensation in the OEE. The maximum OEE is resulted 96.10% from the high of factor A, B, and C.

In the Half-Normal plot, the points lying on the line are noise or normal process variation in our data, while the points in the right from the line are significant effect causing significant changes, which are availability, performance and quality. The highest effect, availability (A) which have absolute value of 20, is plotted at 93.83 % probability, next performance rate (B) and quality (C) having 4.27 and 1.689 respectively, with 80% and 65% probability as well.

ANOVA for selected factorial model

Table 4: ANOVA response model of OEE for Cement mill

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	830.92	3	276.97	1808.63	< 0.0001	significant
A-A	788.58	1	788.58	5149.42	< 0.0001	significant
B-B	36.63	1	36.63	239.19	0.0001	significant
C-C	5.71	1	5.71	37.30	0.0036	significant
Residual	0.6126	4	0.1531			
Cor Total	831.53	7				

The Model calculated F-value which is 1808.63 emphasizes the model is significant.

P-values smaller than 0.0500 indicate that model terms are significant. In this case, both A, B and C are essential model concepts. Values over 0.1000 indicate that model parameters are not relevant.

$$OEE\ (\%) = 82.81 + 9.93A + 2.14B + 0.845C$$

In terms of coded variables, the equation can be used to make assumptions about the response of each factor to given levels. The high levels of the variables are coded by default as +1 and the low levels are coded as -1. Through comparing the component coefficients, the coded equation is helpful for anticipating the relative influence of the variables. Availability (A) and performance (B) are relatively high impactful.

$$OEE\ (\%) = -165.61 + 0.9424A + 0.86B + 0.844C$$

Figure 13: Main effects Availability (A), Performance rate (B) and Quality (C) on OEE

Result

The main effects graph indicates the quality (C) and performance rate(B) hardly effect OEE, while Availability (A) positively affect the OEE of cement mill, ranging availability from 77.33% to 98.4%, OEE is affected in between 75% to 95%.

The plot of the interaction between availability vs quality at their both low-level and high-level spawning OEE from 70.26% to 96.1%.

Crusher

Full factorial of Crusher

The full factorial design is carried out on three factors, which having eight runs, one replicates, one blocks and zero Center points. (Annex 5)

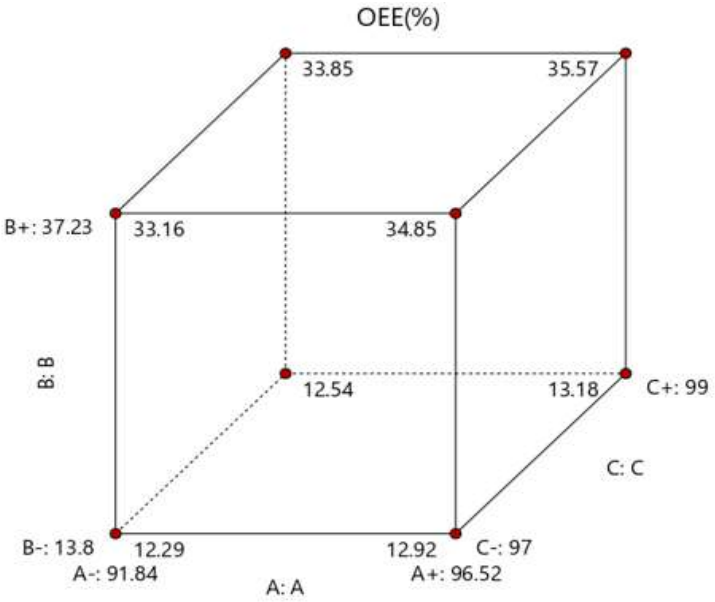


Figure 13: Cube plot of predicted response of OEE for Crusher

As shown in the geometric cube (figure 14), the factor A, B, and C shows their low "- "and high "+" level respectively, and the effect of change in each factor is demonstrated in cube, clearly visible their compensation in the OEE. The maximum OEE is resulted 35.1874% from the high of factor A, B, and C.

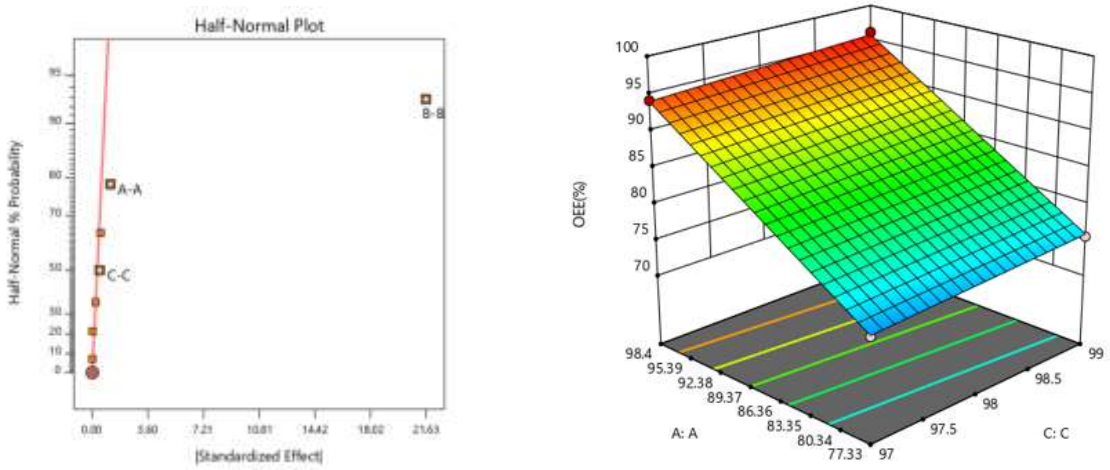


Figure 14: Half-normal plot of effects for OEE

In the Half-Normal plot (figure 14), the points lying on the line are noise or normal process variation in our data, while the points in the right from the line are significant effect causing significant changes, which are availability, and performance. The highest effect, performance rate (B) which have absolute value of 21.625, is plotted at 94 % probability, next availability (A) and quality (C) having 1.17 and 0.48 respectively, with 80% and 50% probability as well.

ANOVA for selected factorial model

Table 5: ANOVA response model of OEE for Crusher

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	938.49	3	312.83	1853.51	< 0.0001	significant
A-A	2.74	1	2.74	16.23	0.0158	significant
B-B	935.29	1	935.29	5541.56	< 0.0001	significant
C-C	0.4620	1	0.4620	2.74	0.1734	
Residual	0.6751	4	0.1688			
Cor Total	939.16	7				

The Model calculated F-value in table 5 which is 1853.51 emphasizes the model is significant. P-values smaller than 0.0500 indicate that model terms are significant. In this case, both A, B are essential model concepts. Values over 0.1000 indicate that model parameters are not relevant.

$$\text{OEE}\ (\%) = 23.55 + 0.5851\text{A} + 10.81\text{B} + 0.24\text{C}$$

In terms of coded variables, the equation can be used to make assumptions about the response of each factor to given levels. The high levels of the variables are coded by default as +1 and the low levels are coded as -1. The coded equation is useful for anticipating the relative influence of the factors by comparing the parameter of coefficients. Coefficient of performance indicates relative impact is greater than rest.

$$\text{OEE}\ (\%) = -47.09 + 0.25\text{A} + 0.922\text{B} + 0.24\text{C}$$

In terms of real variables, the equation can be used to make assertions about the answer for each factor at given amounts.

Result

The main effects graph indicates the quality (C) and Availability (A) hardly effect OEE, while performance rate (B) positively affects the OEE of Crusher, ranging performance from 13.8% to 37.23%, OEE is affected in between 12.29% to 35.57%. However, it's still lacking deliberately speaking in competency, the factory is not utilizing the machinery in lane of its working capacity. And now, in the interaction plot it is illustrated how badly performance (B) effects the OEE in the interaction with the quality (C), the factory should bring this in consideration.

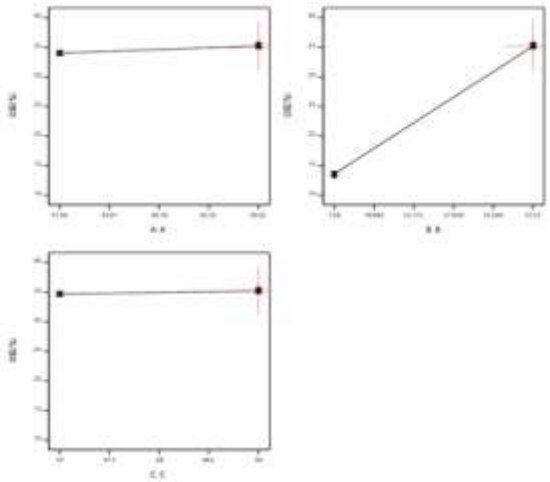


Figure 16: Main effects Availability (A), Performance rate (B) and Quality (C) on OEE

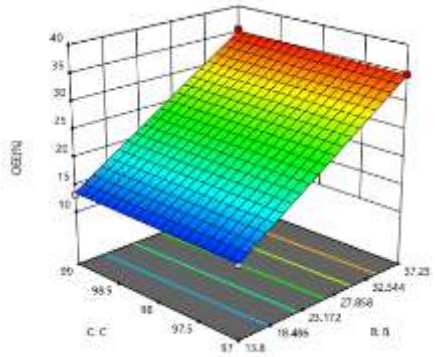


Figure 17: Interaction effects Availability (A), Performance rate (B) and Quality (C) on OEE

The plot of the interaction between performance vs quality at their both low-level and high-level spawning OEE from 12.29% to 33.85%. Design Expert is used to plot a contour & surface plot with experimented values. In the surface plot, OEE changes in terms of availability and performance rate can be observed.

Conclusion

This paper presents model for individual machinery OEE values and most influencing factors are proposed; the enhancement of OEE to improve up to a certainly value, by the probe of most significant factor-performance rate for the Kiln, Raw press and Crusher was very productive, however, availability for Cement mill respectively. In order to compare with the standards to achieve world class standards of OEE, most influencing factor affecting OEE, deliberately significance is indicated by their respective F-values and P-values. The full factorial of DOE resulted into optimized values for the Kiln, Raw press, Crusher and Cement mill of OEE are 97.56%, 90.58%, 35.57%, 96.10% respectively. After considering the machines, the Crusher is found critical, their optimized value OEE was 35.75% having difference of 49.25% for standard 85% OEE, anticipated by availability 96.52%, performance rate 37.23% (with difference of 57.77% with standard 95% performance) and quality 99%. These results, Simulated values of the above analysis will be valuable information to industry.

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Annex 1

Table 6: week 1 Availability

S. No	Equipment	Shift Length(hr.)	Planned Downtime(hr.)	Unplanned Downtime(hr.)	Gross Time(hr.)	Available Time(hr.)	Availability	Availability (%)
1	Kiln	168	8.83	2.5	159.17	156.67	0.984294	98.429
2	Raw Press	168	52.66	0.25	115.34	115.09	0.997832	99.783
3	Cement Mill	168	80.5	19.83	87.5	67.67	0.773371	77.337
4	Crusher	168	2.66	5.75	165.34	159.59	0.965223	96.522

Table 5: week 2 Availability

S. No	Equipment	Shift Length(hr.)	Planned Downtime(hr.)	Unplanned Downtime(hr.)	Gross Time(hr.)	Available Time(hr.)	Availability	Availability (%)
1	Kiln	168	0	0.25	168	167.75	0.998512	99.8511905
2	Raw Press	168	50.58	0	117.42	117.42	1	100
3	Cement Mill	168	105.08	8.92	62.92	54	0.858233	85.8232676
4	Crusher	168	2.25	7.25	165.75	158.5	0.956259	95.6259427

Table 6: week 3 Availability

S. No	Equipment	Shift Length(hr.)	Planned Downtime(hr.)	Unplanned Downtime(hr.)	Gross Time(hr.)	Available Time(hr.)	Availability	Availability (%)
1	Kiln	168	0	2.25	168	165.75	0.98660714	98.66071429
2	Raw Press	168	23.92	21.5	144.08	122.58	0.85077735	85.07773459
3	Cement Mill	168	23.92	8.25	144.08	135.83	0.94274014	94.27401444
4	Crusher	168	4.5	13.34	163.5	150.16	0.91840979	91.84097859

Table 7: week 4 Availability

S. No	Equipment	Shift Length(hr.)	Planned Downtime(hr.)	Unplanned Downtime(hr.)	Gross Time(hr.)	Available Time(hr.)	Availability	Availability (%)
1	Kiln	168	0	0.33	168	167.67	0.9980357	99.8035714
2	Raw Press	168	30.99	18.17	137.01	118.84	0.8673819	86.7381943
3	Cement Mill	168	53.5	1.83	114.5	112.67	0.9840175	98.4017467
4	Crusher	168	0	6.08	168	161.92	0.9638095	96.3809524

Table 8: week 1 performance

Equipment	Processed amount (tons)	Theoretical cycle Time(hrs.)	Total Running Time (hr.)	Performance (%)
kiln	16256	0.0048571	156.67	50.39702406
raw press	16256	0.00333	115.09	47.03491181
cement mill	16256	0.0039	67.67	93.6876016
crusher	16256	0.00166	159.59	16.90892913

Table 9: week 2 performance

Equipment	Processed amount (tons)	Theoretical cycle Time (hrs.)	Total Running Time (hrs.)	Performance (%)
Kiln	13184	0.0048571	167.75	38.17347624
raw press	13184	0.00333	117.42	37.38947368
cement mill	13184	0.0039	54	95.21777778
crusher	13184	0.00166	158.5	13.80784858

Table 10: week 3 performance

Equipment	Processed amount (tons)	Theoretical cycle Time (hrs.)	Total Running Time (hrs.)	Performance (%)
kiln	33684	0.0048571	165.75	98.70682136
raw press	33684	0.00333	122.58	91.50572687
cement mill	33684	0.0039	135.83	96.71471693
crusher	33684	0.00166	150.16	37.23724028

Table 11: week 4 performance

Equipment	Processed amount (tons)	Theoretical cycle Time (hrs.)	Total Running Time (hrs.)	Performance (%)
kiln	28502	0.0048571	167.67	82.56519604
raw press	28502	0.00333	118.84	79.8650791
cement mill	28502	0.0039	112.67	98.65785036
crusher	28502	0.00166	159.59	29.64679491

Annex 2

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:A	B:B	C:C	OEE(%)
4	1	99.85	98.7	97	95.59
8	2	99.85	98.7	99	97.56
7	3	98.42	98.7	99	96.16
6	4	99.85	38.17	99	37.73
2	5	99.85	38.17	97	36.96
3	6	98.42	98.7	97	94.22
1	7	98.42	38.17	97	36.43
5	8	98.42	38.17	99	37.19

Annex 3

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:A	B:B	C:C	OEE(%)
5	1	85.07	37.38	99	31.48
4	2	100	91.5	97	88.75
8	3	100	91.5	99	90.58
2	4	100	37.38	97	36.25
1	5	85.07	37.38	97	30.84
6	6	100	37.38	99	37.00
3	7	85.07	91.5	97	75.50
7	8	85.07	91.5	99	77.06

Annex 4

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:A	B:B	C:C	OEE(%)
5	1	77.33	93.68	99	71.71
3	2	77.33	98.65	97	73.99
7	3	77.33	98.65	99	75.52
1	4	77.33	93.68	97	70.26
4	5	98.4	98.65	97	94.15
2	6	98.4	93.68	97	89.41
6	7	98.4	93.68	99	91.25
8	8	98.4	98.65	99	96.10

Annex 5

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A:A	B:B	C:C	OEE(%)
8	1	96.52	37.23	99	35.57
4	2	96.52	37.23	97	34.85
5	3	91.84	13.8	99	12.54
1	4	91.84	13.8	97	12.29
2	5	96.52	13.8	97	12.92
3	6	91.84	37.23	97	33.16
7	7	91.84	37.23	99	33.85
6	8	96.52	13.8	99	13.18