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Envisaging Maintenance Costs of Hydraulic Press in the Ceramic Industry with Regression Modelling

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Abstract— The increased frequencies in failures of industrial machines cause disorders in planned production schedule ensuing in a financial loss of the company which repeatedly upturns periodic maintenance costs. Due to fronting a superior competition in market place, industrial, production, planning and maintenance engineers continuously attempt to increase production frequency effectively and uninterruptedly. This work basically presents a mathematical approach for originating a regression model for forecasting monthly maintenance costs of hydraulic press model Sacmi 580 installed in Frontier Ceramics Ltd, Pakistan. Being a central production unit of ceramic industry, a comparative research study has been accompanied to predict maintenance costs, generated due to gradual progress of machine usage. For determination of best fit prediction model for the captioned machine, various models were analysed using Minitab version 18 and Microsoft Excel 2016 respectively. Collected data were analysed using four regression models: linear, exponential, power and logarithmic respectively. On the basis of results obtained from regression analysis, it was concluded that the linear model presented better prediction regarding monthly maintenance costs with greater confidence with a smaller amount discrepancy as compare to the other. It was finally recognized that monthly maintenance costs steadily increased with progressive service life of hydraulic press.

Index Terms— Ceramic industries, Hydraulic press, Maintenance costs, Mathematical modeling, Regression analysis,

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1 Introduction

The ultimate goal of company's endeavor is to make revenue through standardized production system, which could be distressed by some substantial elements. It is also factual that every manufacturing unit ties their profits with expenditures necessary for capital growth by scheduling their production system at maximum level, but implication system breakdown is a common case in this perspective [1]. Operational service life and maintenance tasks of a certain machine are the issues unswervingly interrelated with the production schedule, target and revenue outcome [8]. Mathematically machine service life can be expressed using three different approaches:

Service life: This is the maximum time period of full operation. During this stage the machine is impacted by maintenance and repair tasks conducted throughout the machine's life cycle [7]. Profit life: This is the time period where a machine is making a profit [7, 5]. It is the greatest anticipated phase of the life span of machine as beyond this phase the machine will run with a loss due to increased numbers of parts replacement as main elements get worn out rapidly [5]. Economic life: Economic life is cantered on reducing tenure costs with the growth in operating costs [2]. These three approaches are interrelated with machine's

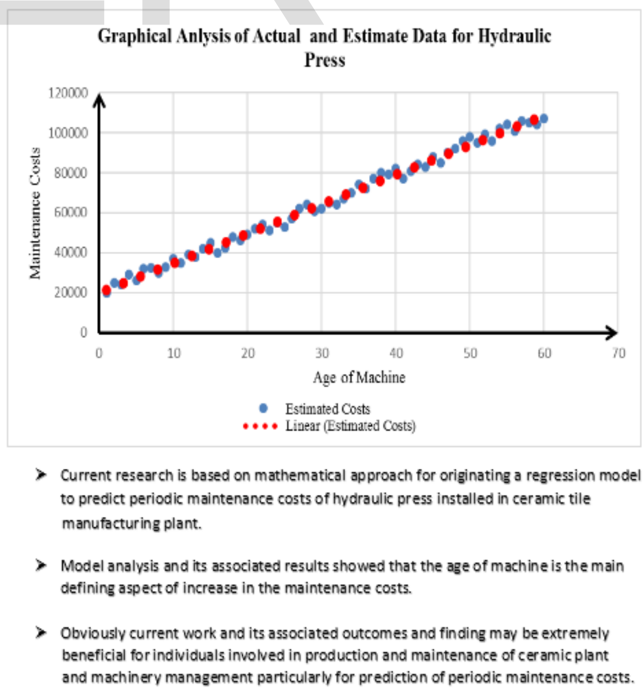

FIGURE 1. A pictorial of relationship between the age of machine and maintenance costs

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productive service life, based on the bathtub curve as illustrated in Figure 2.

After being installed, there is a minor probability of breakdown and failure and it will be running with its full output for a considerable period of time relative to its predictable service life being the function of numerous variables including mechanisms, materials, design, and process [9]. Finally, the frequencies of failure probabilities increase due to parts worn out due to wear and tears of various types [4]. Conventionally, the service life of a machine is limited by two aspects, the physical in which wear and tear decrease the reliability of machine leading to increase maintenance cost and the obsolescence in which the machine is no longer capable to produce products as per company's requirements [10]. However, industrial machines are always subjected to a list of various wear and tear issues due to which the service life of a machine gradually declines [11]. Major causes of wear and tear that affect the service life of machine are abrasion, corrosion, erosion, friction, heat, fatigue and adhesion and impact damage. Even a minor damage created during part manufacturing will becomes a defect that will start a future failure under the wrong environments [12]. Due to poor serviceability of machines the frequency of breakdown increases resulting in loss of production, costly emergency repairs, delays in production schedules besides keeping the men and machinery idle. As per illustration of Figure 3, the costs of break down generally surpass total cost of preventive maintenance while beyond this optimal point, an increasingly higher level of preventive maintenance is not economically justified and it is economical to adopt breakdown maintenance policy [13].

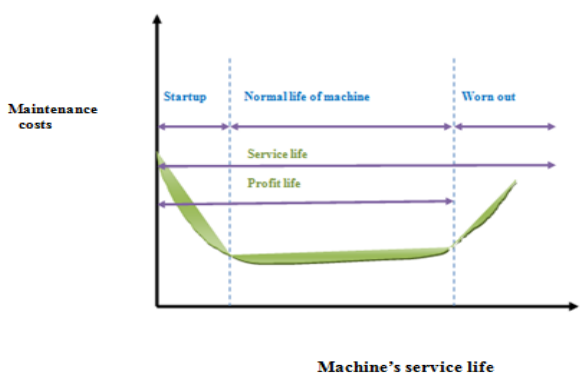

FIGURE 2. Relationship between the three stages of each life-cycle

If at any prime close the required maintenance task is supposed to be M, the particulars of costs pertaining to machine service life and maintenance must be acknowledged. These maintenance costs are costs generated in case of breakdown (downtime due to Idle time cost), costs of spare parts necessary for replacement, cost due to idle labor i.e expenditures of maintenance departments and production Losses due to wasteful operations of machines [6].

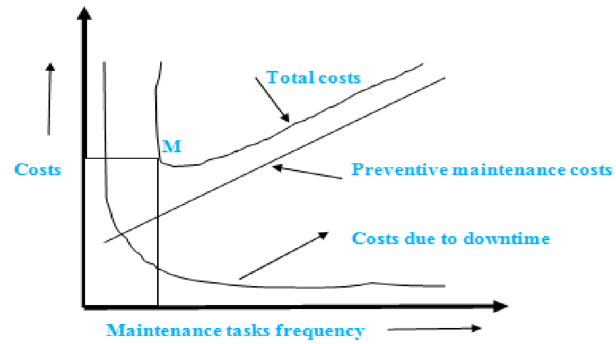

FIGURE 3. Maintenance cost comparison

The aim of this study is to present a prediction mathematical model for developing relationship between maintenance costs and machine service life. The current work may be useful tool for production planners, engineers, policy makers to evaluate the performance of machines for similar industries.

2 REGRESSION ANALYSIS AND MODEL OVERVIEW

2.1 Coefficient of correlation (*r*)

Also known as Pearson correlation coefficient used to compare the weakness and strength of linear relationship between two variables. As the coefficient values are taken between +1 and -1 hence a +1 shows that both the variables have a perfect positive linear correlation ship with a straight line and a positive slope [16]. On the other hand, a -1 will show a negative linear correlation ship with a straight but negative slope using the following expression

$$r = \frac{n\sum(xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum(y^2) - (\sum y^2)]}} \quad (1)$$

2.2 Coefficient of determination (R^2)

An extensively used technique based on taking the ratio between the sum of squares of

$$R^2 = \frac{SS_r}{SS_t} = 1 - \frac{SS_e}{SS_t} \quad (2)$$

Used for checking the appropriateness of regression model. If the two variables X and Y are randomly distributed, then

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R^2 is considered the square of correlation coefficient among these two variables. Hence R^2 is the amount of variances in the given data for regression model. The coefficient always tends to rise in case a certain variable is added to a model however it will not recognize that the later model is better that the old one. If error of sum of squares with in the novel model is limited to a considerable quantity like to the new mean square error, only then the new developed model shall possess a greater amount of mean square error as compared to the older one due to the loss of degree of freedom [19].

2.3 Residual Analysis for model Judgement

Often it is desirable to analyze the strength of any regression model by using regression residual expression

$$e_i = y_i - \hat{y}_i \qquad (3)$$

It is also true that consistently scattered residual plots will show a comparatively worthy fit of model, but keeping in view the individualities of a model's residuals when the studied model is misunderstood [17]. Assuming that the precise model will have the quadratic practice such as

$$y_i = \beta_0 + \beta_1(x - \bar{x}) + \beta_2 x^2 + \epsilon \qquad (4)$$

For instance, if it is supposed that the mistakenly definite linear regression model was supposed to be in the form such as

$$y_i = \beta_0 + \beta_1(x - \bar{x}) + \epsilon^* \qquad (5)$$

Then $\epsilon^* = \beta_2 x^2 + \epsilon^*$ that looks unidentified. In this case error mean will not be equal to zero. It is also clear from quadratic model that

$$b_0 = y_i = \beta_0 + \beta_2 x^2 + \epsilon \qquad (6)$$

While

$$b_1 = \frac{S_{xy}}{S_{xx}} = \frac{\sum_{i=1}^{n}(x - \bar{x})(\beta_0 + \beta_1(x - \bar{x}) + \beta_2 x^2 + \epsilon)}{S_{xx}} \qquad (7)$$

And

$$b_1 = \beta_1 + \beta_2 \frac{\sum_{i=1}^{n}(x)x^2 + \sum_{i=1}^{n}(x)\epsilon}{S_{xx}} \qquad (8)$$

So it is appropriate to calculate $E(b_0)$

$$E(b_0) = \beta_0 + \beta_2 x^2 \qquad (9)$$

Hence, b_0 and b_1 are considered the partial approximations of β_0 and β_1 respectively. The above assumptions for residual analysis present a pure theoretical approach for conducting the t test and F test for possible determination of correlation significance between variables followed by the confidence interval and prediction estimates. In case the assumptions regarding error look doubtful, the significance of the regression bond results might not be effective. Residuals analysis incorporates best evidence about error that helps to highlight whether the assumptions for error are applicable or not [18].

2.4 Linear regression model

Knowing the comparative connection between the two variables, the next step is to establish a regression equation to predict or forecast the variable of interest. Using the equation "y" is the variable whose value is to be determine to forecast while "b" is the regression's slope. The "x" being the independent variable value followed by "a" that represents the intercept of y. Generally linear regression tries to evaluate a particular line which will best fits data while the equation pertaining to that particular line fallouts in the regression equation [15].

$$\hat{y} = ax + b \qquad (10)$$

$$a = \frac{\sum x \sum y - n \sum xy}{(\sum x)^2 - n \sum x^2} \qquad (11)$$

$$b = \frac{\sum x \sum xy - \sum x^2 \sum y}{(\sum x)^2 - n \sum x^2} \qquad (12)$$

$$R^2 = r^2 \qquad (13)$$

2.5 Exponential regression model

Occasionally linear regression may be used with such connections that may not be integrally linear, but becomes linear after a makeover using the following expressions

$$\hat{y} = e^{a+bx} \qquad (14)$$

$$b = \frac{n \sum x \ln y - \sum x . \sum \ln y}{n \sum x^2 - (\sum x)^2} \qquad (15)$$

$$a = \frac{1}{n}\sum \ln y - \frac{b}{n}\sum x \qquad (16)$$

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2.6 Power regression model

Power regression model is a type of non-linear regression model which can be stated as a power regression model of form y, based on the following equation

$$\hat{y} = a.x^b \tag{17}$$

It is clear that exponential model and power model encompass exponents therefore the model is constructed in comparable way. Taking the natural log of both sides of the equation, the following equivalent equation are observed:

$$b = \frac{n\sum(\ln x.\ln y) - \sum \ln x.\sum \ln y}{n\sum(\ln)^2.x - (\sum in.x)^2} \tag{18}$$

$$a = \exp\left(\frac{1}{n}\sum \ln y - \frac{b}{n}\sum \ln x\right) \tag{19}$$

2.7 Logarithm regression model

Data presented through logarithmic modeled may either increasing or decreasing with passage of time and this increase or decrease in data determine whether the logarithmic model is suited or not [14]. While conducting logarithmic regression analysis the following form of logarithmic expression is generally considered

$$\hat{y} = a + b\ln x \tag{20}$$

$$b = \frac{n\sum(y.\ln x) - \sum \ln x.\sum y}{n\sum(\ln)^2.x - (\sum in.x)^2} \tag{21}$$

$$a = \frac{1}{n}\sum y - \frac{b}{n}\sum \ln x \tag{22}$$

3 METHODS AND MATERIALS

Required data for analysis has been collected from maintenance engineering department of FCL which basically include maintenance costs associated with Oil leakage, die damages, spare parts and idle labour. For instance, data of consecutive 60 months from 2007 to 2011were selected. In order to analyse regression models for predicting maintenance costs, the usage of machine considered as independent variable (X) while the maintenance costs as dependent variable (Y) respectively. Modern statistical software packages Minitab 18 and Microsoft Excel 2016 were used for variable comparison, analysis and results overview. Finally, the regression model with the highest coefficient of determination (R^2) was selected as the fitted or best model for prediction of maintenance costs.

4 RESEARCH FINDINGS

4.1 Analysis of maintenance costs

Much of the maintenance costs were generated due to constraints like oil leakage, die damages, spare parts and idle labor respectively. Figure 3 shows the deliberated costs of maintenance of each individual constraint along with percentage portion. It is well clear that the costs contribution of 58% pertaining to high volume of spare parts replacement is the highest observed costs among the other constraints. One of the reasons of this cost constraint is due to aspects like practice of subnormal spare parts followed by inappropriate involvement of inexpert maintenance workforces. The succeeding maintenance cost constraint is associated with idle labor having 23% share of total costs generated from idle operators and workers due to unexpected breakdown of machine. The lowest observed cost constraint sharing 7% is concerned with die damages of hydraulic press. Table 1 shows a full detail summary of maintenance costs calculated in Pakistani currency and taken as dependent variable while the age of hydraulic press in month as independent variable for the period of 2007 to 2011 respectively.

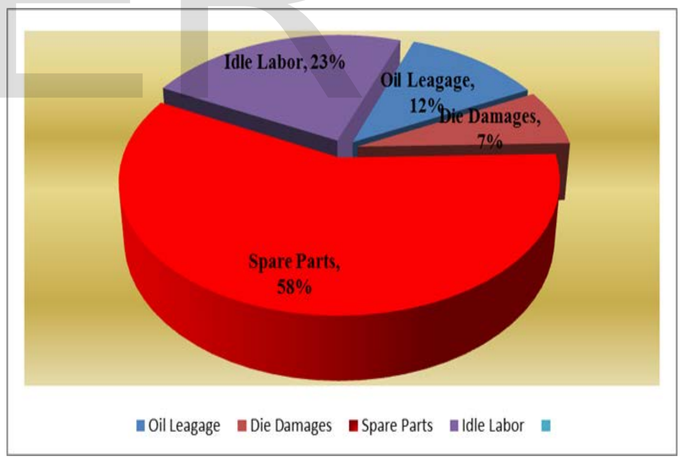

FIGURE 3. Maintenance cost comparison

Table 1: Machine usage and maintenance costs PKR (2007-2011)

Age (Month)	Spare parts	Idle labor	Oil leakage	Die damages	Total
Total	2,266,060	898,610	468,840	273,490	3,907,000

The above consequences of database have additionally utilized for investigation of pattern, regression and presentation of mathematical model.

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4.2 Analysis of trend line function

Figure 5 presents the graphical comparison of trend line results outlining the forecasting equations with corresponding coefficient of determination (R^2) for analyzing different regression models i.e linear, power, logarithmic and exponential respectively. It is desirable to choose the correlation that best describes the data base with accordance to the R^2 value. As it closer approaches to 1, there will be better fit of data showing a good relationship among variables. On the other hand, the value of (R^2) also helps to choose the best prediction model for the given variables.

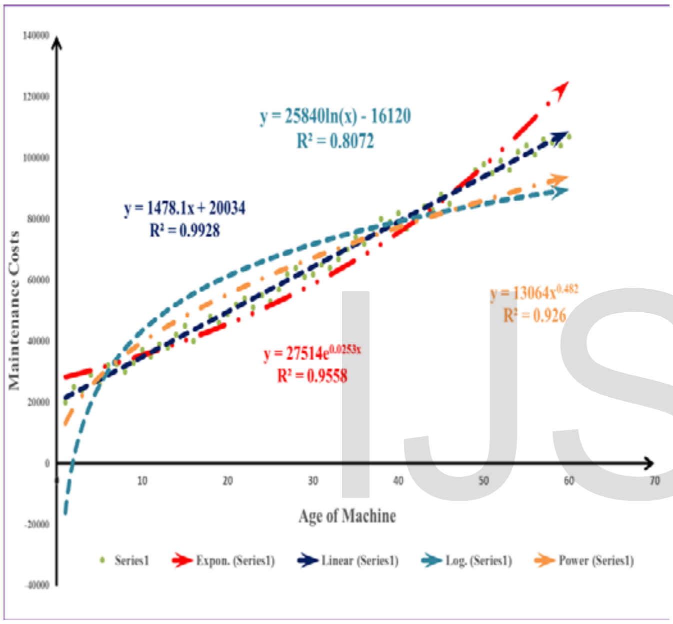

FIGURE 5. Trend lines comparison

From Figure 5 it is well observed that linear regression line of maintenance costs increases with increase in machine usage which specifies that maintenance costs gradually increase with as the machine's service life continuing progress.

5 REGRESSION ANALYSIS WITH MINITAB

Table 2 presents different mathematical models that were computed on the basis of data presented in Table 1 which basically demonstrates the model description, coefficient of determination (R^2) and residual sum of squares results obtained for hydraulic press. The analysis and results clearly show that the maximum significance of coefficient of correlation (R^2) between the other associated mathematical models is found in linear model (R^2 = 0.9928) and it designates its greater conformity through the real database trend in contrast with the former two mathematical models (power and exponential).

Table 2: Minitab summary of regression models and estimate of parameter for hydraulic press

Model Description	Summary of Mode		Estimates of Parameter		
	R^2 value	F value	a	b	c
Linear	0.9928	7964.55	1478.1	20034	
Power	0.9260	725.78	13064	0.482	
Exponential	0.9558	1254.21	27514	0.0253	
Logarithm	0.8072	242.82	25840	16120	

6 MINITAB RESULUTS

6.1 Output prediction report

For prediction model normally a 95% confidence level is considered best which shows that the number of samples selected from the population, the CI (confidence intervals) of the samples would contain the mean response by 95%. On the other hand, prediction interval indicates that the researcher could be 95% confident that the interval contains the value of a single new observation. The red fitted line shows the predicted Monthly maintenance costs (Y) for analyzed age of machine (X). The blue dashed lines show the 95% prediction interval as presented in Figure 6.

6.2 Diagnostic report

Minitab 18 diagnostic report basically assists for recognition the data analysis by provision of extra detail, for instance outliers that should be explore for investigating any noteworthy variance. As per Figure 7 observations, the data points are located randomly on both sides of zero which clearly indicates that the identification of large residuals that have a strong influence on the fitted regression line.

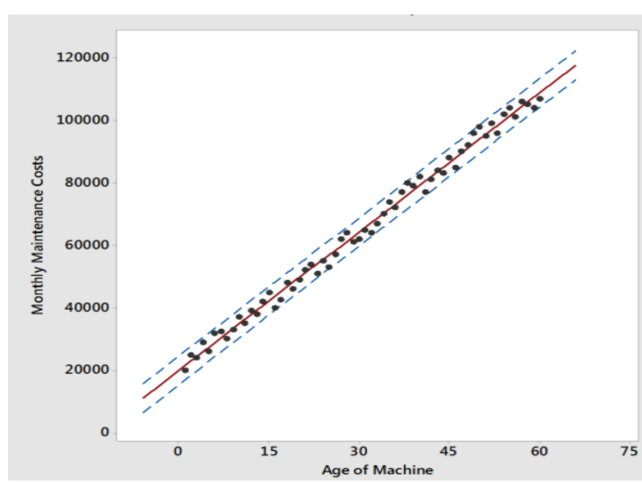

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FIGURE 6. Prediction Plot for Monthly Maintenance Costs

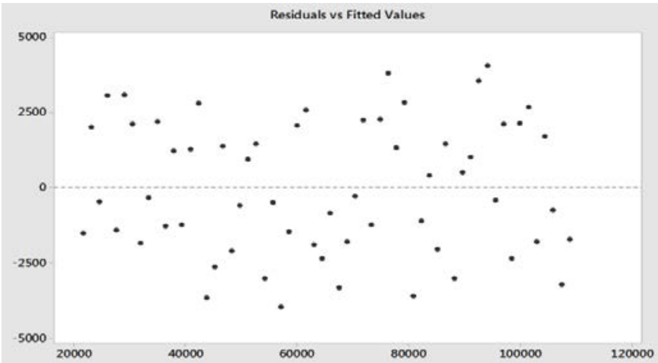

FIGURE 7. Identification of large residuals influencing on the fitted regression line

6.3 Model summary report

Final summary brings a really true picture of conducted analysis and its associated outcomes. If p-value is found to be less than 0.001 then it tells that the studied regression model is statistically significant hence the relation between the maintenance costs and age of machine is obviously significant ($p < 0.05$). Similarly, % of variation explained by the model shows that there is 99.28% of the variation in monthly maintenance costs can be explained by the regression model as shown in Figure 8. The positive correlation (R Square = 0.9928) indicates that when the age of machine increases, monthly maintenance costs also tends to increase. Finally, the fitted equation for the linear model that describes the relationship between X and Y is

$$Y = 20034 + 1478\,X \qquad (23)$$

Since the model fits the data well and possesses the greatest coefficient of correlation, hence this equation can be used to predict monthly maintenance costs for a value for age of machine that corresponds to a desired value or range of values for monthly maintenance costs.

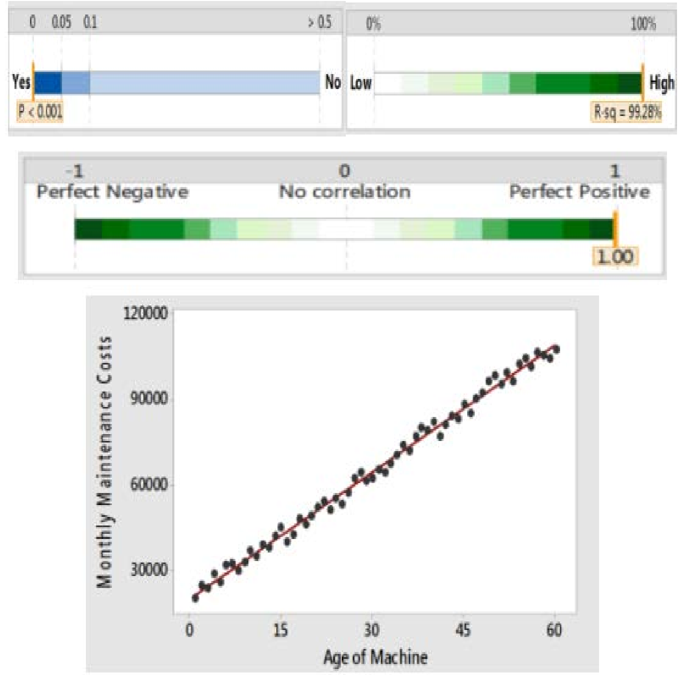

FIGURE 8 Minitab Model Summary Report for Monthly Maintenance Costs and Age of Machine

6 MODEL PREDICTION – COMPARISON OF ACTUAL AND ESTIMATED COSTS

The Judgment among the actual and estimated maintenance costs data attained by the concluding prognostic model (Linear) for Hydraulic press is hereby shown in Figure 9. which shows a very small alteration.

Table 3: Excel summary of linear regression model for hydraulic press

Regression Statistics	
Multiple R	0.996378613
R Square	0.99277034
Adjusted R Square	0.99264569
Standard Error	2221.783668
Observations	60

ANOVA	df	SS	MS	F	Significance F
Regression	1	39315376619	39315376619	7964.507	8.59599E-64
Residual	58	286306714.8	4936322.669		
Total	59	39601683333			

	Coefficient	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	20034	580.908	34.488	2.4E-40	18871.6	21197.2	18871.6	21197.278
X Variable	1478	16.5624	89.244	8.5E-64	1444.95	1511.25	1444.9	1511.2584

This difference in cumulative rate of maintenance costs may be recognized to some decisive facts like overall machine service life, rapid increase in wear and tear, intrinsic deficits followed by mismatched processes related to their control and competences.

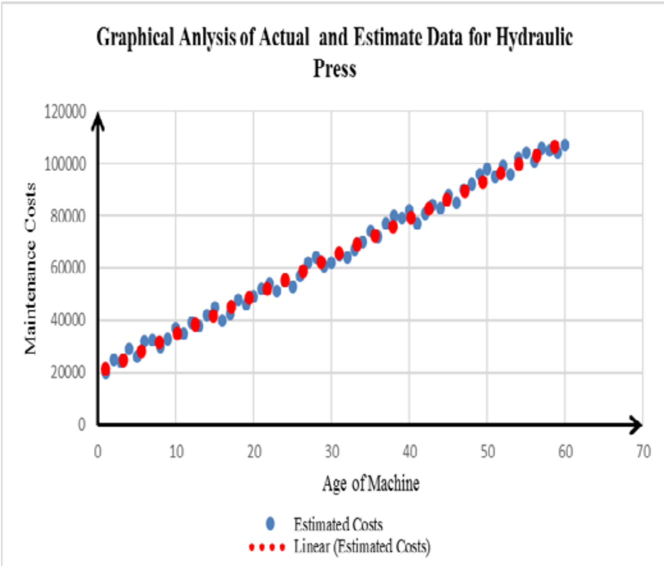

FIGURE 9. Actual and estimated data comparison using linear model.

6 DISCUSSION

Forecast and prediction models for industrial maintenance costs and replacement measurements are mostly dependent on such issues as investigation technique enactment with necessary time extents, amount as well as nature of samples in a given research study, required techniques and steps of processes with recommended operational environments, maintenance engineering and management, materials quality followed by the necessary skills of operators for running the specific machine or equipment. Based on analysis and results obtained during this research specified that normal monthly maintenance cost gradually increased with the usage of service life of machine. Similarly obtained results correspondingly established that linear model which has been established for hydraulic press has the accumulated monthly based working usage which is the independent variable and main influential factor for monthly maintenance costs being the dependent variable in this particular case. Obviously current work and its associated outcomes and finding may be extremely beneficial for individuals involve in production and maintenance of ceramic plant and machinery management particularly for prediction of their plant periodic maintenance costs in Pakistan and abroad as well. On the other hand, this work will deliver organization decision makers and policy establishers of other associated silicate industries dealing with similar type of machine for impending phase of planning regarding hydraulic press serviceability to concerned at fairly inferior maintenance cost.

7 CONCLUSION

Some of the conclusions drawn from this study: Current work and its analysis has recognized that maintenance cost pertaining to captioned hydraulic press installed in Frontier Ceramics Ltd, gradually increased with accordance to gradual progress in service life. Similarly, the selected model showed that the age of machine is the main defining aspect for increase in the maintenance costs. Finally, for predicting monthly maintenance cost of hydraulic press might be perfectly projected with the use of the ensuing linear regression mathematical model.

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