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Cost Estimation for Bench Drilling Phase of Diamond Wire Sawing Technique for Granite Mining

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Abstract:

One of the reasons mining projects are facing sudden closure and premature termination is the financial uncertainties associated with these project. Mining projects differ from each other e.g. on the basis of utilized human and technological resources. This paper has two objectives, first is to estimate different cost components as percentage of the total cost and second is to propose an optimum cost model each for the bench drilling phase of granite mining through diamond wire sawing technique. For this purpose total cost is divided into six components e.g. fuel cost, labour cost, consumables cost, maintenance cost, depreciation cost and insurance cost. Cost components estimation reflects that fuel cost is the highest incurred cost components followed by consumables' cost and labour cost. Depreciation and insurance costs are fixed costs and hence no influence on production. Pearson correlation suggests that production has strong correlation with all cost components excluding depreciation and insurance costs. Regression analysis suggests that only labour cost, and maintenance cost have significant influence on production. Once these costs are known the planners and investors can develop more accurate and realistic economic feasibility plans of dimension stones mining.

Index terms:

Cost component analysis, Pearson correlation, regression analysis, cost modeling, Bench drilling, dimension stone mining

I. INTRODUCTION

Dimension stones are the rocks excavated with one or more mechanically furnished side(s) for the purpose of cutting and (or) shaping to a specific size for structural or decorative purposes in construction and monumental applications [1, 2, 3, 4, 5], with main features of the appearance, and ability to yield rectangular blocks of suitable dimensions [6, 7], durability and resistance to decay, porosity, water absorption, and grain size. Granite, marble, onyx, quartzite etc fall into the category of dimension stones. Calcareous materials (marbles, travertine, limestone etc), siliceous materials (granites, quartzite and sandstones) and slate are some classes of these dimension stones [6]. Conventional techniques of dimension stone extraction include wedge and feather technique, drill and blast technique and expansion mortar technique while mechanized modern techniques include diamond wire sawing, drum cutters and chain sawing. Diamond wire sawing technique has been the most widespread technology for dimension stone extraction, especially marble extraction since the end of the seventies, however, some problems are associated with the abrasive properties of hard rocks making the use of diamond wire very difficult [8]. But the finishing quality of the product and the percentage recovery as compared to the other method makes this method cost-effective [9] and widely used in the dimension stone quarrying sector [10,11].

The production cycle of dimension stone extraction through the diamond wire technique consists of five phases i.e. bench drilling, bench cutting, bench dropping, bench slicing/ squaring and product loading. In most of the cases where bench height is small, bench dropping phase is skipped. In bench drilling phase, three mutually perpendicular holes are drilled along three virtual axes of Cartesian coordinate system. The dimension of these holes depends on the dimensions of bench needed to detach from the deposit. In this way, three virtual Cartesian planes form. Bench drilling phase aims to create passage for the diamond wire to cut the stone in three planes. Drilling unit consists of DTH drill machine and a compatible compressor. In case when one of the three holes is small, jack hammer can be used to drill the hole.

Pakistan has been blessed with the abundance of good quality dimension stone deposits; however, the country does not stand among the globally top producer of mined stones. One of the main reasons is the utilization of conventional mining techniques, primarily drill and blast. Investors do not have a realistic perception about the capital and operational costs of modern techniques and they have reservations about the cost-effectiveness of diamond wire sawing technique. There is a need to develop cost estimation models so that the investors and planners have clear idea about the operational and fiscal parameters of mechanization of their project. The objectives of this research paper are:

- To estimate the percentage of different cost components incurred during bench drilling phase of diamond wire sawing technique of dimension stone extraction.
- Develop an optimum cost model to estimate the operational costs of bench drilling phase of diamond wire sawing technique of dimension stone extraction.

Value added products of diamond wire sawing technique can help Pakistan to be among the top producers of dimension stone round the globe.

II. LITERATURE REVIEW

The cost theory suggests the different ways to arrange cost into different groups such as direct cost and indirect cost, or capital cost (investment cost), operating cost [12], and general and administrative (G&A) cost, etc. [13]. In order to determine the degree to which the mine operation will be feasible, these costs are to be estimated accurately, (e.g.) on the basis of available information of a previous similar project [14]. The Activity-Based Costing (ABC) Approach is a cost and management tool for decision-making on product mix [15].

Globally, mining companies are currently experiencing erratically high cost trends in their overall mining and associated costs [16, 17]. Drilling, one of the critical and important operations of every hard rock mine contributes about 15 % of the overall mining cost in some mining operations [18]. Labour cost is the overall associated with the wages, benefits and taxes of a worker [19]. Insurance of a worker can be categorized as labour cost but as companies also insure machinery too, insurance cost can be dealt separately. Maintenance cost of drilling machines is a significant cost issue [20] and it can be as much as 40% of the total production cost [21]. Maintenance can be key factor in the long-term profitability of a company as well-developed and organized maintenance strategies can increase productivity [22].

Budeba, Joubert, & Webber-Youngman (2015) discussed different cost estimation approaches for mining operations such as statistical approaches, online approaches, comparative approach and itemized approach [23]. Sayadi, Lashgari, & Paraszczak (2012) suggested that many mining cost estimation handbooks utilize the statistical approaches of capital and operating cost estimation including O'Hara models; multiple regressions based on principal component analysis; an econometric model; and the use of single-variable regression model [24].

Regression analysis study was carried out during 2008 to estimate the Australian Average Capital Costs (ACC) for an open-pit mine development [12]. Regression analysis technique of cost estimation utilizes historical cost data to formulate a relationship between the product costs and the value of certain variables so that the model can be used to forecast the cost of a new product [25]. Sontamino & Drebenstedt (2013) presented cost estimation models for coal mining operations using system dynamics. Although, the models dealt with certain components of costs, however one of their models presented during 2013 can be applicable for the cost estimation of other types of open pit mines [26].

1.1. Area of Study:

M/s Indus Mining (Private) Limited has been one of the pioneers to introduce diamond wire sawing technology in Pakistan. The company has one of the mines of dolerite (commercial name: black granite) in Tehsil Oghi, district Mansehra. Table 1 shows the coordinates of the lease area in which this mine is situated. The longitude of the deposit ranges from 72º54′30″ E to 72º55′40″ E approximately while latitude ranges from 34º26′10″N to 34º26′35″ N approximately. Diamond wire sawing technique is employed in this mine for the extraction of blocks as main product and boulders as by-product.

Table 1: Coordinates of the lease area of dolerite (black) granite owned by M/s Indus Mining (private) Limited.

Point	Easting	Northing
A	1143050	3193999
B	1143050	3195828
C	1142108	3195828
D	1142108	3193999

There is one active working level for producing the blocks and boulders. The mine has four depleted levels and one temporarily abandoned level. For drilling, the pneumatic operated Marini Driller DTH, and Chinese Y-19 and Y-24 jack hammer drills are used at the mine site. Two compressors, PDS-390S (Airman) and CP-350 (Chicago Pneumatics), provide compressed air supply to operate the drill machines. For bench cutting, the machinery unit consists of a 50 hp wire cutter (Marini) and a generator of 207 KVA (Cummins). Another combination of the same specification wire cutter and a Cummins 150 KVA generator is used for bench slicing purposes are used for loading of mined products. The loading machinery unit consists of Excavators PC-400 (Komatsu), LC-280 (Hyundai), and front end loader, FEL, 980-B (Caterpillar), a derrick crane with the loading capacity of 35 tons, and an electric generator of 60 KVA to provide supply to the crane.

III. MATERIALS AND METHODS

The production and costs data of the last four and a half years (N=54) were taken from the company's record. For this research, the cost is divided into six major components i.e. fuel costs, labour costs, depreciation costs, consumables cost, maintenance costs, and insurance costs. The costs data included the details of each of the five cost component shown in figure 1. Percentage of each of the cost components is estimated for bench drilling phase in the form of pie chart. Table 2 briefly describes the example and estimation criteria (if any) of these cost components considered for this research.

Table 2: Cost components of wire sawing technique of dimension stone extraction: Explanation and estimation criteria (if any).

Cost Component	**Explanation**	**Estimation Criteria**
Fuel Cost	Related to diesel, and lubes utilized by the machines. Lubes include engine oil, hydraulic oil and C oil (or transmission) etc.	NA
Consumable cost	Related to Non-repairable items e.g. drill bits, drilling rods, diamond wire and joints, loader tyres, excavator chain accessories etc.	NA
Labour cost	Related to worker and staff salaries, their overtime extra payment from company to worker based on production in order to motivate worker other facility for worker include mess, laundry, travelling and mobile and internet expenses.	NA
Maintenance cost	Proactive and reactive maintenance of machinery/ equipments e.g. engine overhauling, hydraulic pump overhauling etc.	10 % of the capital cost (annually).
Depreciation cost	Machinery/ equipments and Re-usable items	40% of salvage value based on 5 years' life of project.
Insurance cost	Related to the crew and machinery.	25000 per labour & 50000 per machine annually.

In order to calculate the different correlations and regression model, SPSS [version 17] is used. Bivariate (Pearson) correlation method is used to find the correlation between production and other costs variables. Positive value shows direct correlation while negative values show reverse correlation. The value greater than 0.5 reflects strong correlation (maximum value 1.0), while the value less than 0.5 reflects weak correlation.

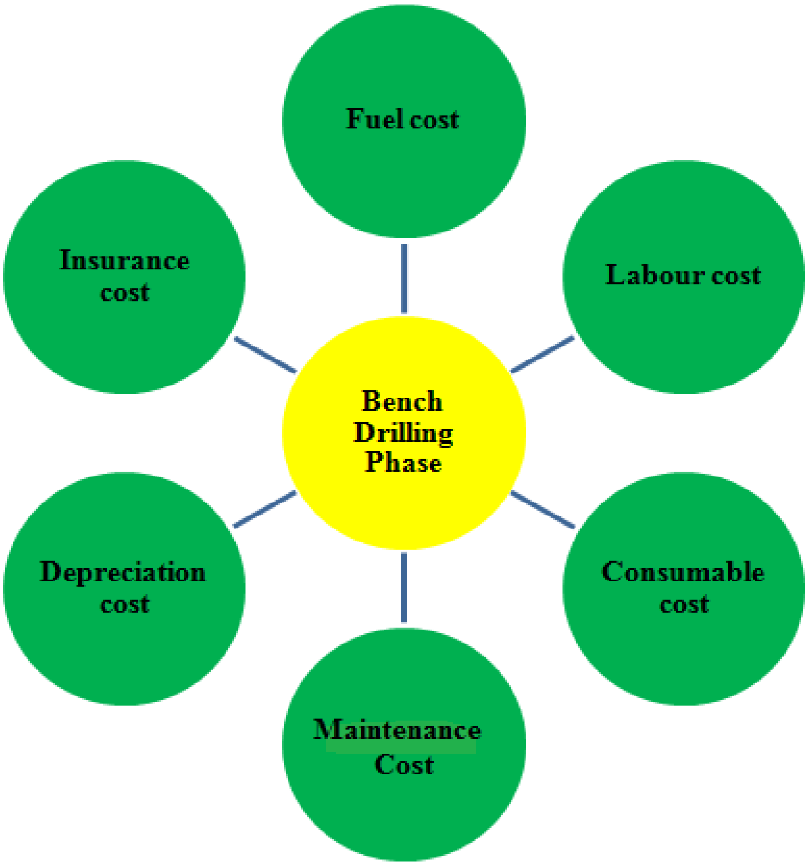

Figure 1: Method of cost estimation (% component analysis) adopted in this research (**Source:** self-extract).

Linear regression is used to develop cost estimation model with production as dependant variable and fuel cost, labour cost, Consumable cost, R&M cost each as independent variable. The value of R^2 is a reflection of the percentage of data described by an optimum model of cost estimation. General regression model between production and all four cost components (regression equation) is defined in equation 01.

$$P_d = \beta_0 + B_i X_i \qquad (01)$$

Where P_d is production (tonnage) during a phase and X_i is the four cost components. Depreciation and insurance costs remain constant irrespective of production outputs. Hence these two parameters have no role to play in cost modeling. B_0 is constant of equation and B_i are standardized regression coefficients of different parameters. B_0 (standardized coefficients- beta) value defines the magnitude of the impact of the associated parameter. The more the value of β_i near to 1, the more will be the impact of associated cost head. Positive values of coefficients suggest that there is a direct variation while negative values suggest inverse variation between the dependent variable and independent variables.

If F is the fuel cost, L is the labour cost, C is the consumables' cost, M is the maintenance cost; equation 02 is the optimum cost model in this research for the diamond wire sawing technique of dimension stone extraction.

$$P_d = \beta_0 + B_2(F) + B_3(L) + B_4(C) + B_5(M) \qquad (02)$$

It must be noted that depreciation and insurance costs are not shown in this equation as they are constant and have no relationship production.

IV. Results

4.1. Cost Component Estimation:

Historic data of the relative share of these cost components is shown in the form of pie chart in Figure 2. On the basis of the obtained data from the field, the percentage share is generalized for the broader implication (i.e. for all granite family). Fuel cost, with a relative share of 35%, is the highest overall cost incurred during bench drilling, followed by consumable cost (27%) and labour cost (20%) as shown in Figure 2. Depreciation cost is 10%, Maintenance (R&M) cost is 5% while Insurance cost is only 3% of the total cost incurred during bench drilling phase.

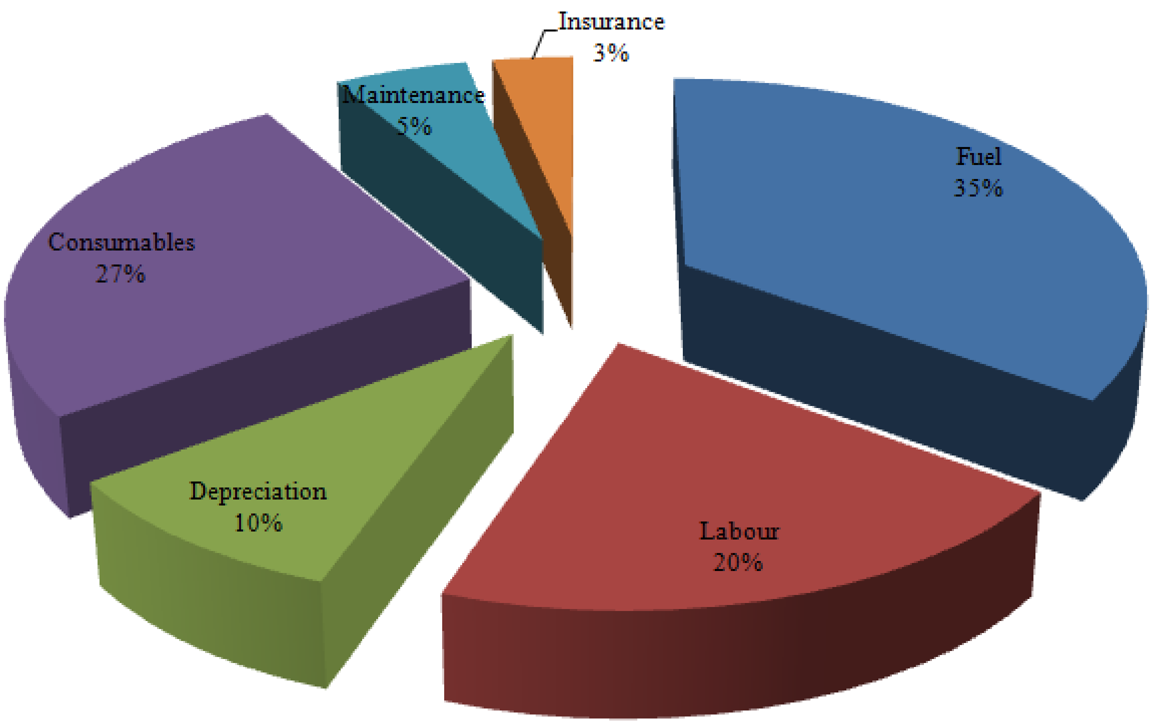

Figure 2: Pie chart showing relative share of the bench drilling cost components.

4.2. Correlations analysis:

Table 3 gives the correlations of production with different cost components incurred during the bench drilling phase. As depreciation cost and insurance cost are fixed costs, therefore there could not be any correlation between these variables and production and hence not mentioned in further discussion. The *p*-value of 2-tailed significance of all these correlation is 0.000

which show that all of these correlations are statistically significant. The data shows that production has the strongest correlation with labour cost (0.865) followed by maintenance cost (0.703). Both fuel cost and consumables cost has equal and strong correlation of 0.662 with production. Production has a significant linear positive relationship with all cost parameters which means that production will increase if all cost parameters increase and vice-versa. One may also deduce that the operations have been performed optimally and the resource utilization is optimal in the process.

Table 3: Correlation of production and production cycle costs in Bench drilling phase (N=53).

		Fuel	**Labour**	**Consumable**	**Maintenance**
Production	Pearson Correlation	0.662	0.865	0.662	0.703
	Sig. (2-tailed)	.000	.000	.000	.000
	Correlation is significant at the .01 level (2-tailed).				

Figure 2-a, to 2-d are the graphical representation of correlation between production and different cost variables.

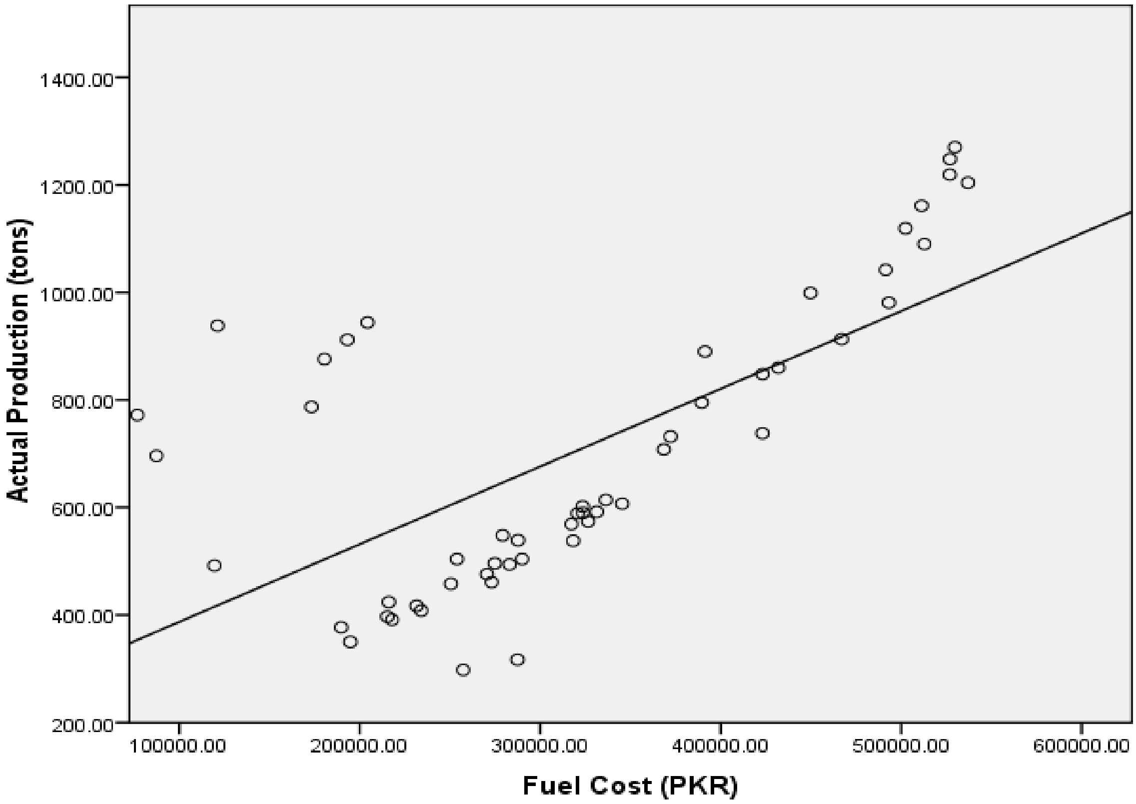

Figure 3-a: Graphical representation of correlation between production and fuel cost (r = 0.662).

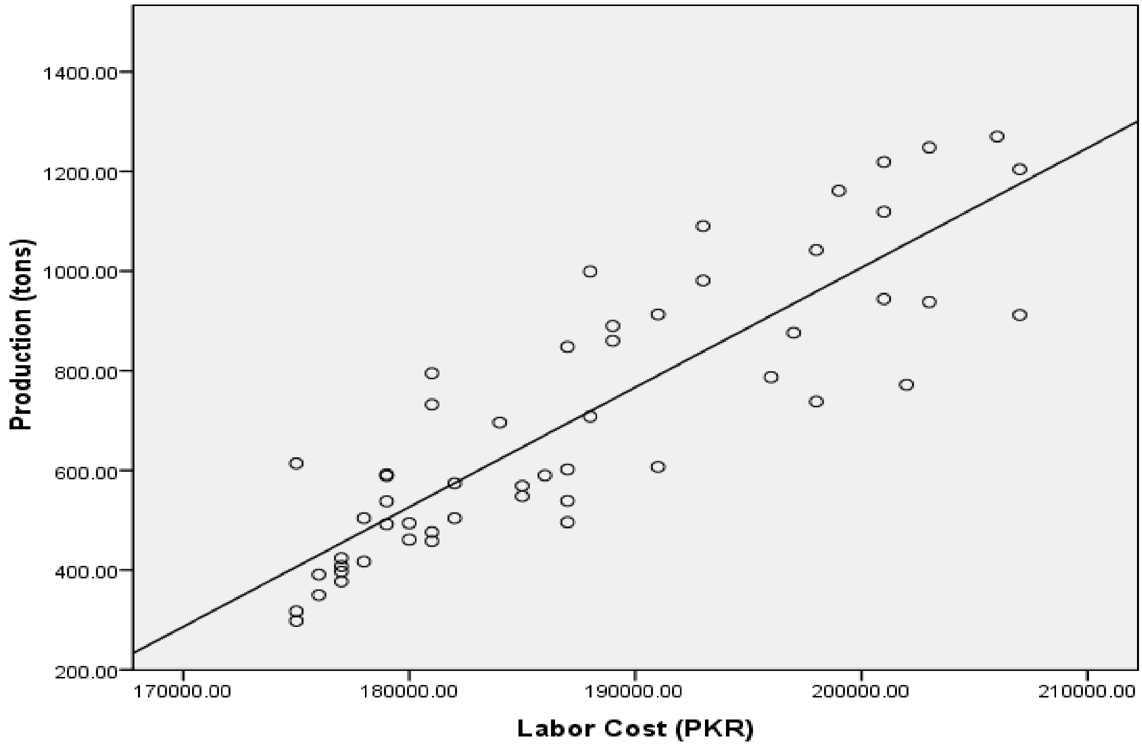

Figure 3-b: Graphical representation of correlation between production and labour cost (r = 0.865).

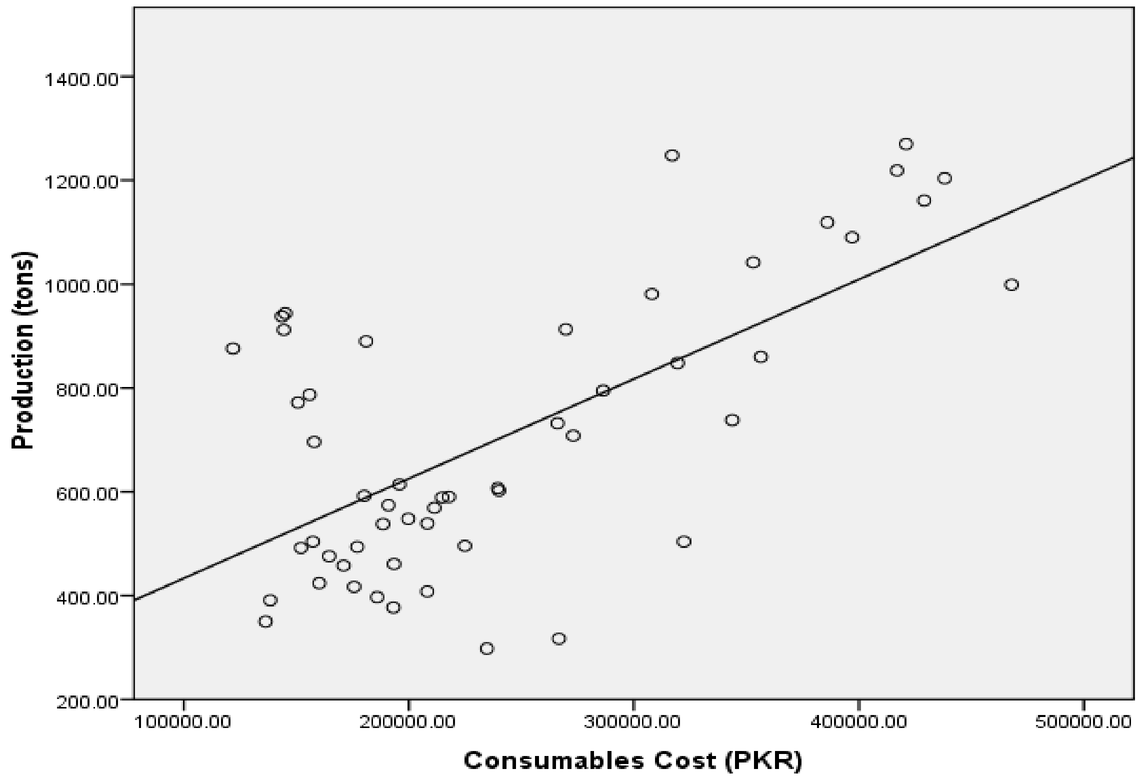

Figure 3-c: Graphical representation of correlation between production and consumables cost (r = 0.662).

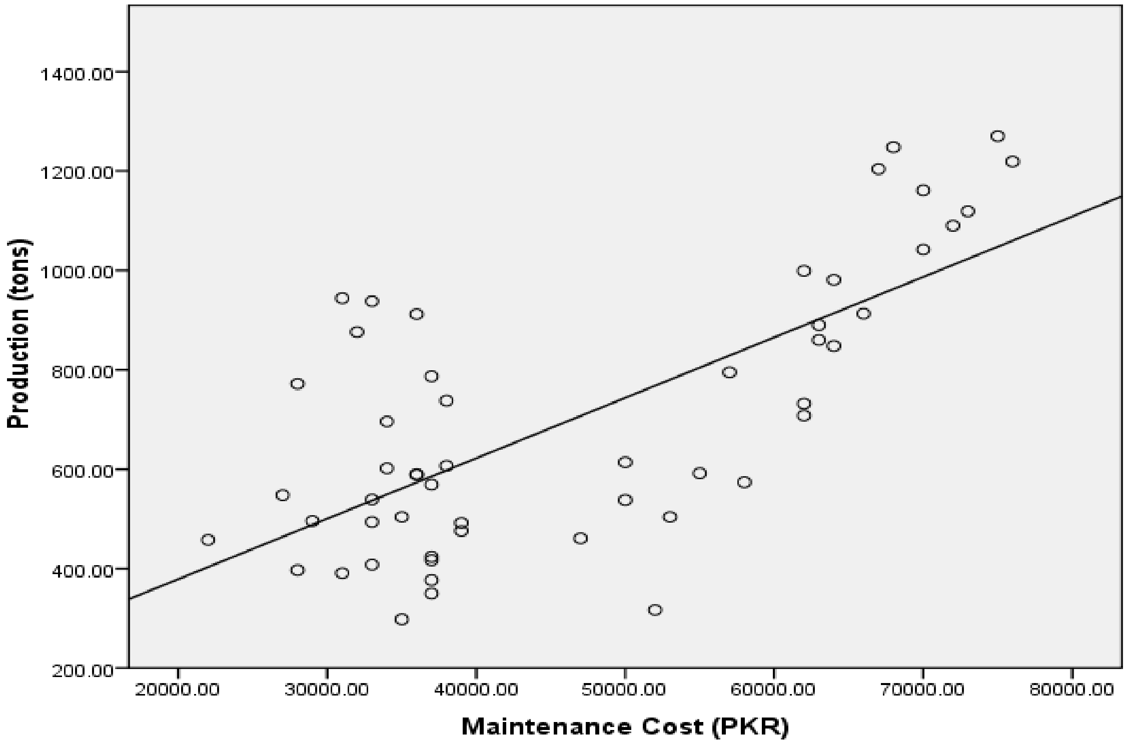

Figure 3-d: Graphical representation of correlation between production and maintenance cost (r = 0.703).

4.3. Cost estimation modeling:

Although Pearson correlation value between production and cost variables suggest that production is strongly associated with these variables but the extent of the relative influence of each of the cost parameters on production needs further analysis. For this purpose bivariate linear regression analysis is performed with production as dependant variable and different cost parameters as independent variables. Table 4 shows the results of this regression analysis. Adjusted R^2 value of this model is 0.923 which suggests that more than 92% of the variance in the data is explained by this model.

Table 4: Relationship between production and bench drilling cost components.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta (β_i)		
1	(Constant)	-3293.394	218.574		-15.068	.000
	Fuel cost	9.03E-5	.000	.041	0.431	.669
	Labour cost	.019	.001	.698	15.813	.000
	Consumables cost	1.406E-5	.000	.005	0.058	.954
	Maintenance cost	.007	.001	.411	5.289	.000
Dependent Variable: Production			R^2 = 0.923			

From table 4, it can be inferred that the relationship of production with labour cost, and maintenance cost is highly significant as p value for both is 0.000, however, production has no significant relationship with both fuel cost and consumable cost as p value are remarkably higher than the common alpha level of 0.05. The results do not necessitate the insignificant relationship between production, fuel cost and consumables cost. Although the fuel costs should have a strong relationship with the output production but there may be circumstances when the one only bench hole drilled through a jack hammer can be sufficient for wire to detach it from the rest of the deposit. In such cases, fuel consumption and production have no significant relation. Some more reasons may be poor record keeping of fuel consumption, compressor operational inefficiency mechanical problems etc.

The optimum production-cost model should not have fuel cost and consumables cost. Table 5 shows the results of new regression analysis with production as dependant variable and only labour cost, and maintenance cost.

Table 5: Optimum model (labour cost, and maintenance cost only)

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta (β_i)		
1	(Constant)	-3313.501	209.660		-15.068	.000
	Labour cost	.020	.001	.703	16.667	.000
	Maintenance cost	.008	.001	.448	10.628	.000
Dependent Variable: Production				$R^2 = 0.923$		

For both labor and maintenance cost $p < 0.05$, hence the both of these have significant influence on production. If P_d is the production (dependent variable), L represents labour cost, M represents maintenance cost (as independent variables); equation (3) is the optimum regression model for the bench drilling phase is as follows:

$$P_d = 0.020L + 0.008M - 3313.501 \qquad (3)$$

The value of R^2 is still 0.923 which means that more than 92% of the variance is described by regression model given in equation 3. Positive B values of both independent variables show that there is a direct relation between production and these two variables. Equation 3 shows that for one unit increase in the labour cost, Production will increase by 0.020 units for vice versa. Similarly, for one unit change in maintenance cost production will increase by 0.008 units.

The values of standardized coefficients suggest that a one standard deviation increase in labour cost leads to a 0.703 standard deviation increase in the predicted production. Similarly, a one standard deviation increase in maintenance cost leads to a 0.448 standard deviation increase in predicted production. The beta coefficient values also suggest that the relative influence of labour cost on production is more than 1.5 times stronger than that of maintenance cost.

4.4. Model Validation:

The value of R^2 is 0.923 which shows that the model accounts for more than 92% of the production variance which is good enough to deduce that the model is valid for production prediction.

The predicted production values for these data were estimated through the model defined in equation 3. These predicted production values are plotted against the actual production values as shown in figure 4. The error in predicted values is represented by the distance of each data point from the plotted diagonal line. The point lying on line shows zero difference between the actual and estimated production.

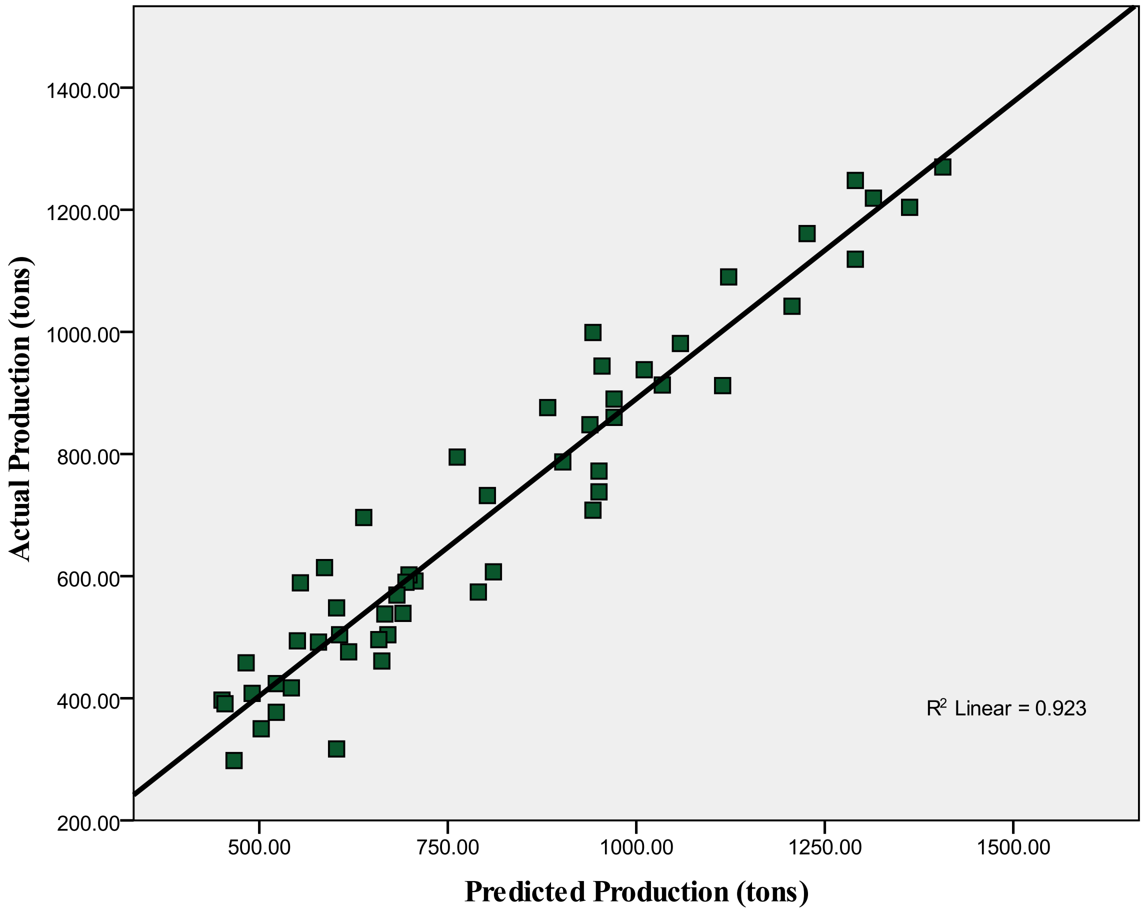

Figure 4: Predicted production values versus actual production values for equation 4.

Hence the model defined in equation 3 can reliably predict the production cost incurred during the bench cutting phase of diamond wire sawing technique of dimension stone mining.

V. Conclusion

Fuel cost is approximately one third, consumable cost is approximately one fourth and labour cost is approximately one fifth of the total cost incurred during bench drilling phase of dimension stone mining through diamond wire sawing technique. Depreciation, insurance and maintenance costs account for almost one fifth of the total cost. Pearson correlation suggests that there is a strong correlation between production and all cost components. Regression analysis show that labour cost, and maintenance cost have significant and strong influence on production while the fuel cost, and consumables cost have insignificant influence on production.

The cost component analysis and cost estimation model for the bench drilling phase of production cycle of diamond wire sawing technique of dimension stone extraction can help the planners and investors to prepare more accurate and realistic feasibility reports hence minimizing the chances of premature termination of these mining projects due to fiscal constraints.

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