Mediation analysis of fuel cost on maintenance cost and production- bench drilling phase of diamond wire sawing technique of Stone Extraction

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Abstract:

Maintenance cost is the expenses incurred for either or both of proactive and reactive maintenance. There is a moderate and statistically significant correlation between maintenance cost and production. Fuel cost is the expenses incurred as diesel and lubricants' consumption. When production is regressed on maintenance cost, the regression model is statistically significant and maintenance cost has a statistically significant and moderate influence on production. This paper aims to find the mediation effect of fuel cost on the relationship between production and maintenance cost. Pearson correlation suggests that fuel cost has statistically significant and strong correlations with both of these variables. When production is regressed on maintenance cost and fuel cost for the mediation analysis of fuel cost, the regression model suggests that fuel cost has statistically significant and strong influence on production but in this model maintenance cost has statistically insignificant and negligible influence on production. This shows that fuel cost has mediation effect on the relationship between maintenance cost and production.

Index terms:

Fuel cost, maintenance cost, mediation analysis, bench drilling, diamond wire sawing

I. Introduction

Bench drilling is the first phase of diamond wire sawing technique of dimension stone extraction. Different costs incurred in this phase can be divided into five major components i.e. fuel cost, labour cost, maintenance cost, depreciation cost and insurance costs. Both diesel consumption and lubricants consumption are function of operating time. There are two types of maintenance, proactive maintenance and reactive maintenance [1]. Proactive maintenance may be a pre-planned, scheduled activity while the reactive maintenance may not a pre-planned activity but to make the machine operational after sudden breakdown due to any unforeseen reason. An unforeseen damage to the machine or some part/ accessories of it may also cause spillage or wastage of fuel.

Various researchers have analyzed different operational parameters [2, 3, 4, 5, 6, 7, 8] but least research has been done on the relationship between cost components and production [9] and especially the influence of different cost components on each other. This paper aims to find whether there is any mediating effect of fuel cost on the relationship between maintenance cost and production for the bench drilling phase of diamond wire sawing technique of dimension stone extraction.

II. Material and Method

Hypothesis testing approach is used in this research. This research focuses only on fuel cost and maintenance cost as major cost components incurred during bench drilling phase of stone extraction through diamond wire sawing. Fuel cost includes the expenses incurred due to diesel consumption to operate compressor. Operators prefer to estimate diesel consumption on hourly basis to analyze the performance of the machine. Fuel cost also includes the expenses due to the consumption of lubricants associated with the compressor operations e.g. engine oil and hydraulic oil etc. Generally lubricants' change is a function of time e.g. engine oil needs to change after 150 operational hours of compressor and hydraulic oil needs to change after 2,000 to 2,500 operational hours (manufacturers' proposed). Maintenance cost includes the expenses incurred for both proactive and reactive maintenance of compressor and the drilling machines. Monthly data of production and both fuel cost and maintenance cost for a span of four and a half years has been taken from Black granite quarry of M/s Indus Mining (Private) Limited. The raw data was checked for presence of any outlier entries.

Production has a strong and positive correlation with both maintenance cost and fuel cost incurred during bench drilling phase of dimension stone mining [9]. This research is based on the assumption that fuel cost mediates the relationship between maintenance cost and production. One prerequisite condition for the mediation analysis is that all of these three variables,

production, maintenance cost and fuel cost must have a moderate to strong and statistically significant correlation (p-value ≤ 0.01). For the purpose of hypothesis testing, the significance level (p-value) is set as 0.01. Null and alternate hypothesis are developed to find the presence of any mediation effect of fuel cost on the relation between maintenance cost and production. Two regression models were developed to test hypothesis. First regression model includes production as dependant variable and only maintenance cost as independent variable as shown in figure 1.

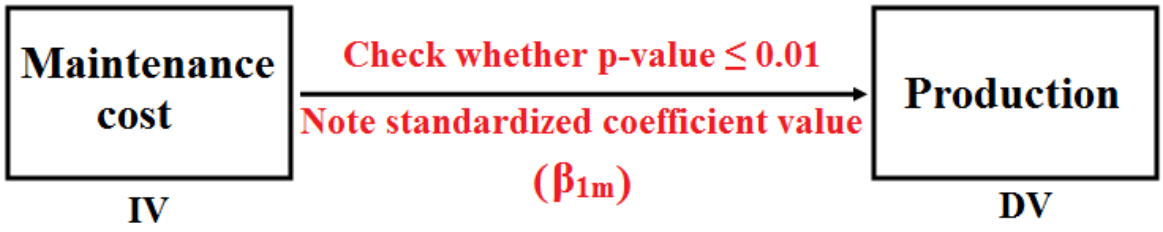

Figure 1: Regression model (mediator variable excluded). (IV: Independent variable, DV: Dependent variable)

There was no inclusion of fuel cost (possible mediator) in this model. Standardized Beta value of maintenance cost (β_{1m}) and its significance was noted. Second regression model includes production as dependant variable and maintenance cost and fuel cost (possible mediator) as independent variables as shown in figure 2.

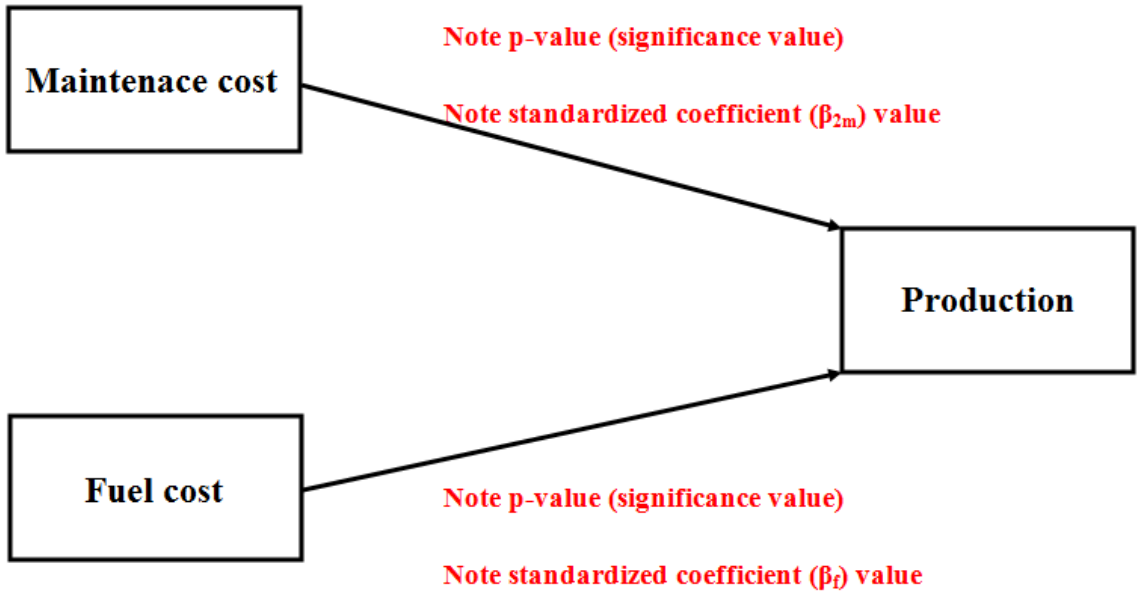

Figure 2: Regression model (mediator variable included).

Standardized Beta value of maintenance cost and its significance was also noted. The p-value and standardized beta coefficient value of maintenance cost in both models were compared. If the standardized beta coefficient value of maintenance cost in second model (β_{2m}) reduces and becomes insignificant, there will be a mediation effect of fuel cost on relationship between maintenance cost and production as shown in figure 3.

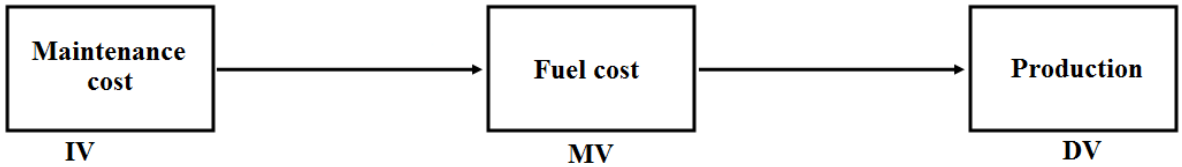

Figure 3: Mediation model used in this research (IV: Independent variable, MV: Mediator variable, DV: Dependant variable).

Null hypothesis is proposed as follows:

Null hypothesis:

"For the bench drilling phase of diamond wire sawing technique of dimension stone mining, fuel cost does not mediate the relationship between maintenance cost (independent variable) and production (dependant variable)". **Condition 1: $\beta_{2m} \geq \beta_{1m}$. Condition 2 (optional): p-value of maintenance cost in 2nd model > 0.01.**

Alternate hypothesis:

"For the bench drilling phase of diamond wire sawing technique of dimension stone mining, fuel cost mediates the relationship between maintenance cost (independent variable) and production (dependant variable)." **Condition 1: $\beta_{2m} < \beta_{1m}$. Condition 2 (optional): p-value of maintenance cost in 2nd model ≤ 0.01**.

In order to accept any of the above two hypotheses, either or preferably both conditions should fulfill.

III. Analysis

First of all three variables of mediation model were tested for Pearson-correlation. Table 1 shows the magnitude and significance level of Pearson correlation. From table 1, it can be deduced that all correlations are statistically significant (p-value ≤ 0.01). Production has a strong correlation with fuel cost (r = 0.664) and moderate correlation with maintenance cost (r = 0.365). Similarly, there is a strong and significant correlation between maintenance cost and fuel cost (r = 0.538). Hence the pre-requisite condition of statistically significant and moderate/ strong correlation between three variable of the tested model fulfills.

Table 1: Pearson correlations between production, maintenance cost and fuel cost (N=54).

		Production	Fuel cost	Maintenance cost
Production	Pearson Correlation (r)	1		
	Sig. (2-tailed)			
Maintenance cost	Pearson Correlation (r)	0.365**	1	
	Sig. (2-tailed)	.000		
Fuel cost	Pearson Correlation (r)	0.365**	0.538**	1
	Sig. (2-tailed)	.007	.000	
**. Correlation is significant at the 0.01 level (2-tailed).				

Regression analysis will be done with maintenance cost as independent variable and production as dependant variable. Table 2 shows that the ANOVA test (and hence the regression model) is statistically significant. R^2 value of 0.133 reflects that the model accounts for only a little more than 12% of the variation in the data.

Table 2: ANOVA test results (IV: Maintenance cost; DV: Production).

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	525245.414	1	525245.414	7.977	.007[a]
Residual	3424117.420	52	65848.412		
Total	3949362.833	53			
a. Predictors: (Constant), Maintenance cost					
b. Dependent Variable: Production					
$R^2 = 0.133$					

Table 3 shows the regression analysis results where production (dependant variable is regressed on Maintenance cost (independent variable).

Table 3: Regression analysis results (IV: Maintenance cost; DV: Production).

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta (β_i)		
1	(Constant)	475.805	86.201		5.520	.000
	Maintenance cost	.005	.002	0.365	2.824	.007
Dependent Variable: Production			$R^2 = 0.133$			

The p-value for maintenance cost is 0.007 which is less than 0.01. This suggests that the influence of maintenance cost on production is statistically significant. Hence the relationship of maintenance cost (independent variable) and production (dependant variable) can be tested for mediation. The beta value (standardized coefficient) is 0.365 which suggests that if there is only maintenance cost in the regression model, for 1 standard deviation in maintenance cost, there will be 0.365 standard deviations in production.

In order to check the mediation effect of fuel cost, the production is regressed on both variables of fuel cost (expected mediator) and maintenance cost (dependant variable). Table 4 shows the ANOVA analysis results. The p-value of this regression model is less than 0.01 which shows that this model is also statistically significant. R^2 value for this model increases to 0.442 which suggests that this regression model accounts for 44.2% variation in the data.

Table 4: ANOVA test results (IV: Maintenance cost, Fuel cost; DV: Production).

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	1743684.078	2	871842.039	20.159	.000[a]
Residual	2205678.756	51	43248.603		
Total	3949362.833	53			
a. Predictors: (Constant), Fuel cost, Maintenance cost					
b. Dependent Variable: Production					
$R^2 = 0.442$					

Table 5 shows regression analysis results of this model where production (dependant variable) is regressed on both maintenance cost and fuel cost (independent variables).

Table 5: Regression analysis results (IV: Maintenance cost, Fuel cost; DV: Production).

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta (β_i)		
1	(Constant)	228.182	84.005		2.716	0.009
	Fuel cost	.001	.000	0.010	0.083	0.934
	Maintenance cost	.000	.002	0.659	5.308	0.000
Dependent Variable: Production			$R^2 = 0.442$			

From table 5, it is observed that the influence of fuel cost on production is statistically significant (p-value<0.01) and strong (standardized beta coefficient value = 0.659). On the other side, the previously statistically significant influence of maintenance cost on production has now become statistically insignificant (p-value= 0.934>0.01) and the influence has also decreased ((standardized beta coefficient value = 0.010). Following conditions of mediation fulfill:

- After the introduction of mediator in the regression model, the influence of mediator (fuel cost) on dependant variable (production) is strong and statistically significant.
- The influence of independent variable (maintenance cost) on dependant variable (production) becomes statistically insignificant and weak.

Hence, the results reject null hypothesis and accepts the alternate hypothesis which states that:

"For the bench drilling phase of diamond wire sawing technique of dimension stone mining, fuel cost mediates the relationship between maintenance cost (independent variable) and production (dependant variable) (i.e. p-value≤0.01)".

IV. Conclusion

This research deduces that maintenance cost first affects fuel cost which eventually affects production. The reason for affect of maintenance cost on fuel cost may be the reactive maintenance when lubricants (especially hydraulic oil) pipes get damaged thereby causing spillage and drainage of lubricants from the pipe lines. Lubricants line may damage due to strike of a stone or hot weather. Once the lubricant drains, there will be a need to refill the lubricants' storage vassal again for smooth working of pumps etc. Similarly frequent leakages from O-rings of lubricants' pipe may also be the reason of excessive lubricants' consumption affecting the overall fuel costs. One other notable reason may be the complete overhauling of hydraulic pump and/ or hydraulic assembly which results in complete, unscheduled change of hydraulic oil in the storage tank.

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