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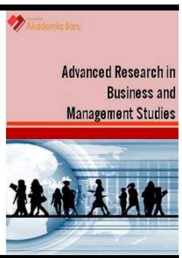

The Impact of Kiln Downtime on the Variable Cost Elements of Clinker Production - A Case Study

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George Decruz[1,*] , Habibah @ Norehan Haron[1]

[1] Razak Faculty of Technology and Informatics Universiti Teknologi Malaysia, 54100 Jalan Sultan Yahya Petra, Kuala Lumpur, Malaysia

ABSTRACT

The overall cost of maintenance has been proposed by researchers as a tool for strategic decision making to identify the most economic maintenance works to be carried out. This can meet an organization's objective to drive down the total cost of production. The review of the literature identified components that should be considered, and amongst these are the efficiency losses which arise in the cement factory under study resulting from kiln downtime. The kiln downtime days resulting from equipment failure has seen a progressive increase over the 10-year period from 2008 to 2017 in the kiln under study. There has been a parallel increase in the variable cost per ton clinker and an increase in the fixed cost per ton clinker.The efficiency losses in the kiln related to the energy consumed because of non-productive periods during cooling and subsequent re-heating are hidden under overall variable costs. Research was carried out based on the historical data from the years 2008 to 2017 to identify the relationship and impact of kiln downtime on variable cost components. The results indicate that the relationships are significant and therefore the impact of maintenance failure on efficiency losses needs to be considered in maintenance decision making.

Keywords:
Variable cost, Downtime, Heat consumption, Power consumption, Maintenance failure, Clinker, Cement

1. Introduction

This research is part of a study to develop a framework utilizing total cost of maintenance failure for the prioritization and identification of equipment maintenance required in one of the kilns of a cement plant in Malaysia. Clinker is a semi-finished intermediate product in the manufacture of Portland Cement. Clinker is manufactured through the crushing of limestone and shale and the subsequent grinding and burning of a proportioned mix of limestone, shale, silica and ferrum bearing laterite also known as raw meal in a pyro-processing unit comprising the preheater, kiln and cooler. The pyro-processing unit utilizes fuel oil/diesel for start-ups and as a back-up for coal which is the principal fuel, other alternative fuel sources are also used. The general process flow of clinker production and the energy inputs are illustrated in Figure 1.

The study is prompted based on preliminary analysis which showed that over the period from 2008 to 2017 there have been corresponding increases in the number of days of kiln downtime and the variable cost of clinker, this analysis utilized the input costs of 2017 as a base [1]. This increase in cost can therefore be solely attributable to an increase in consumption rates of the inputs for

* *Corresponding author.*
E-mail address: gedec58@gmail.com (George Decruz)

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production. This is shown in Figure 2. This study seeks to find a relationship between kiln downtime and the variable cost elements that make up the variable cost structure of clinker.

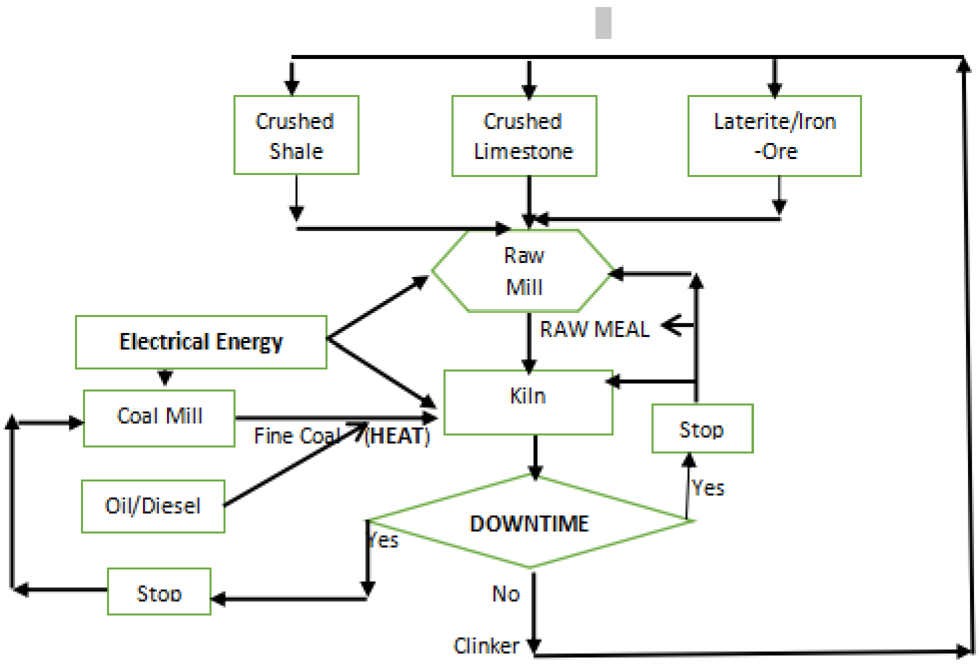
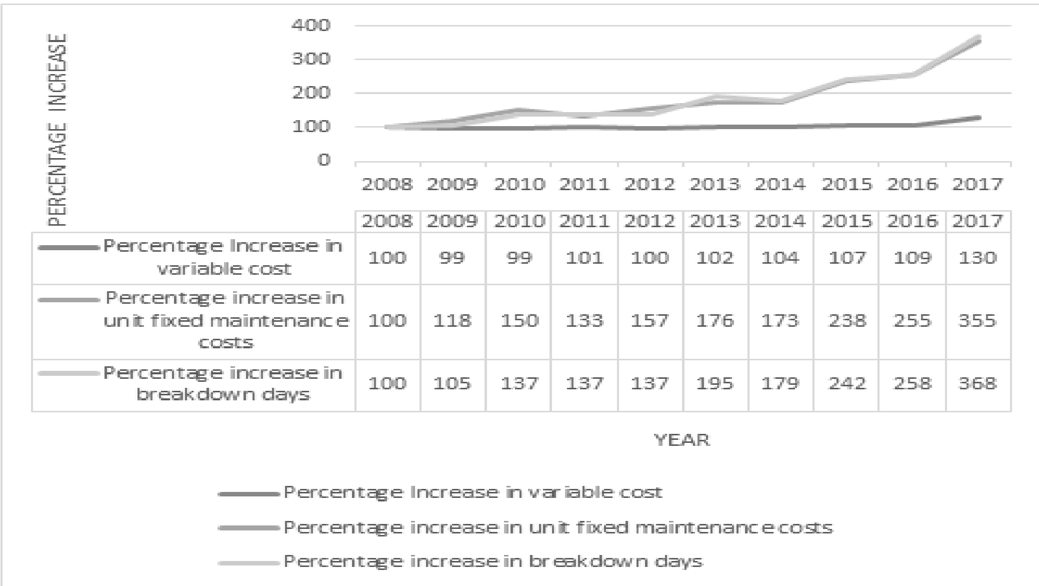


Fig. 1. Process flow for clinker production with energy inputs



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Percentage Increase in variable cost	100	99	99	101	100	102	104	107	109	130
Percentage increase in unit fixed maintenance costs	100	118	150	133	157	176	173	238	255	355
Percentage increase in breakdown days	100	105	137	137	137	195	179	242	258	368

Fig. 2. Percentage increase in costs compared with percentage increase in breakdown days

The significance and utilization of cost of maintenance failure as a tool in assessing the performance of maintenance has been elaborated on by researchers. Simoes *et al.*, [2], in a literature review summarized that cost was the most commonly used assessment of maintenance performance and was utilized in 15 percent of the articles reviewed. Bevilacqua and Braglia [3], postulated that maintenance cost can range from 15 per cent to 70 per cent of overall maintenance cost.

Unscheduled maintenance downtime has been identified as one of the key lagging maintenance performance indicators in a robust literature review carried out by Kumar *et al*., [4] on a review of key maintenance performance metrics. Salonen and Deleryd [5] introduced the concept of “cost of poor maintenance” modelled on the well-established concept of “cost of poor quality”. Mitchell *et al*., [6] found that improved production costs are one of the significant outcomes arising out of the adoption of good maintenance practices and so determines business performance. Alysouf [7], based on a study of Swedish industries utilizing a balanced scorecard approach, identified performance efficiency improvements resulting from maintenance improvements as increasing returns on investment. Weinstein and Chung [8], surmised that the various costs associated with equipment failure should include the costs associated with production interruptions. Peimbert-Garcia *et al*., [9] developed a cost of maintenance failure model to include opportunity losses resulting from loss of revenue as well as infant mortality costs resulting from premature failures after preventive maintenance, as well as any other costs, not included. They however fell short of identifying these other costs which are albeit industry specific. Wudhikarn [10] put forward the concept of Overall Equipment Cost Loss, OECL, where the OECL would also be affected by the performance efficiency of the equipment. The identification of equipment failure and its costs so as to optimize maintenance practices has been explored by Carazas and Souza [11] and elaborated on by Darabnia and Debichela [12]. The studies require the determination of the cost of maintenance which includes the impact of maintenance on energy consumption and how the energy efficiency can be improved by maintenance practices. In the case of the cement plant under study, the variable cost indicators for energy consumption reflect overall performance efficiency, but there is no distinction in the overall variable cost breakdown that distinguishes between capacity related performance efficiency as determined based on well-established methodologies [13,14] and performance efficiency losses related to the unscheduled failure of kiln equipment. This paper describes a study to identify these downtimes related performance efficiency losses.

2. Methodology

A preliminary study was carried out and the following variable cost elements were identified as having a significant correlation with kiln downtime at a confidence level of 95%,

i) Heat consumed in the production of clinker, HC.
ii) Electricity consumed in the kiln expressed in kilowatt-hour per ton clinker, EC_{spK}
iii) Electricity consumed in the raw mill grinding process expressed in kilowatt hour per ton clinker, EC_{spRM}.
iv) Electricity consumed in the coal mill grinding process expressed in kilowatt hour per ton clinker, EC_{spCM}.

The relationship of these variable cost elements with downtime were then analyzed for the period 2008 to 2017, utilizing regression techniques.

The heat consumed per month, HC, is identified as the sum of heat consumed strictly for production, HC_{prod}, heat consumed due to efficiency losses resulting from unscheduled stoppages, HC_{effL}, and the heat consumed resulting from preventive maintenance outages, HC_{prev}. HC_{effL}, can be expressed as follows in equation 1, with the exclusion of the months during which there were preventive maintenance outages.

$$HC_{effL}=HC- HC_{prod} \tag{1}$$

HC, was obtained from the Plant Production Monthly Report, HC_{prod} was obtained from the Plant Daily Production Report by first identifying all the days with full 24 hour operation, determining the ratio for heat consumed, HC_{24}, and clinker produced for full twenty four operation days, $Prod_{24}$, and multiplying it with the total clinker production for the month, $Prod_T$. This is expressed as,

$$HC_{prod}=(HC_{24} \times Prod_T)/Prod_{24} \tag{2}$$

The above equation 2 assumes that the operational factors that influence heat consumption of production, such as the chemistry of raw meal, quality of coal, leakages of air into the system [14.15] will remain constant during the month. The heat efficiency losses, HC_{effL}, determined for each month utilizing equations 1 and 2 were analyzed with Minitab 18 software utilizing regression analysis with HC_{effL} as the response variable and the predictors considered for the model to be the downtime for the month, together with kiln output and calorific value of coal. The kiln downtime data was extracted from the Yearly Plant Breakdown Report while the operating parameters were extracted from Plant Monthly Report. The regression model is expressed below in equation 3,

$$HC_{effL}=f[DL_{24},PR_K,CV_{CO},] \tag{3}$$

where DL_{24} is the downtime based on the capping of all single event downtime that exceeds 24 hours to 24 hours. The heat consumed is measured in Mega calories.This capping reflects the maximum impact of downtime on the kiln heating up time based on standard heating up practice in the plant. PR_K and CV_{CO} are the operating parameters that were considered, production rate of clinker and calorific value of coal respectively.

In the case of electricity consumption, a different approach was taken based on the availability of only monthly meter readings. For each of the unit operations namely the kiln, raw mill and coal mill the specific electricity consumption per ton clinker measured in kilowatt hour per ton clinker, are used as the response variable in a model that has as the predictors the kiln downtime with and without any capping of single event downtime that exceeds 24 hours as well as other operating parameters including production rates, coal calorific value in the case of the coal mill and the unit specific downtime. The specific power consumption data as well as data with respect to the operating parameters were obtained from the Monthly Production Report and the regression analysis was carried out using Minitab 18. The general form of the model in the case of the kiln is as shown in Equations 4 and 5,

$$EC_{spK/RM/CM}=f[EC_{spP},EC_{speffL}] \tag{4}$$

$$EC_{spK/RM/CM}=f[PR_{K/RM/CM},CV_{CO},DL,DL_{24},D_{RM},D_{CM}] \tag{5}$$

where $EC_{spK/RM/CM}$ is the overall specific energy consumed in the operating unit, EC_{spP} is the specific electrical energy consumption for production and EC_{speffL} is the specific energy consumption as a result of the efficiency losses related to downtime. Equation 5 describes the general regression model that was tested utilizing the predictors such as the kiln downtime, DL; production rate for the specified unit operation, $PR_{K/RM/CM}$; coal calorific value, CV_{CO}; raw mill specific downtime not associated with kiln downtime, D_{RM} and D_{CM}, coal mill specific downtime not associated with kiln downtime.

3. Results and Discussion

The results of the regression analysis for the variable cost elements are as presented in Table 1

Table 1
Summary of results of the regression analysis

Variable Cost Element	Regression Model	R^2	p-value of predictors
HC_{effL}, Mega calories	$HC_{effL}^{0.50} = 488.9 + 10.81DL_{24};\ DL_{24} \geqq 2.0$	71.44	$DL_{24}<0.0001$
EC_{spK}, kWh/ton clinker	$EC_{spK} = 91.31 - 0.3640PR_K + 0.0349D_K$,	77.90	PR_K and $D_K<0.001$
EC_{spRM}, kWh/ton clinker	$EC_{spRM}=47.36 - 0.06548PR_{RM} + 0.01182D_K + 0.00982D_{RM}$	58.60	$PR_{RM}<0.001$ $D_K<0.001$ $D_{RM}<0.025$
EC_{spCM}, kWh/ton clinker	$EC_{spCM} = 15.20 - 0.04571PR_K + 0.0023192D_K - 0.000369CV_{CO}$	74.95	$PR_K<0.001$ $D_K<0.003$ $CV_{CO}<0.025$

In each of the models the introduction of kiln downtime improves the R-squared and the variance inflation factors (VIF) of the predictors is below 1.5 indicating low multicollinearity.

The heat losses resulting from 10 hours downtime amounts to 356,409 Mega calories or an equivalent diesel consumption of 35,640 litres. The incremental impact of kiln downtime on incremental power consumed is in the ratio of 15:5.1:1 for kiln:raw mill:coal mill. This reflects the idling time incurred during a kiln stoppage and re-heating of the machinery for the different processes. The idling time is the longest in the kiln because of the need for cooling and re-heating prior to re-commencing production, whilst machinery in the coal mill is shut down relatively fast for safety reasons as it needs to be operated under inert conditions. The raw mill has a process fan which is interlocked with the kiln and which cannot therefore be stopped during cooling.

The raw mill specific downtime, D_{RM}, is a predictor for the specific power consumption in the raw mill, EC_{spRM}, whilst the coal mill specific downtime is not a significant predictor in the case of coal mill specific power consumption. This is because coal mill specific downtime, D_{CM}, is very small compared with kiln downtime as any extended stoppage of the coal mill will cause a kiln stoppage because of the limited stock of ground coal unlike the raw mill process where there is a buffer stock of raw meal in silos.

A 10 hour kiln downtime will result in an incremental 0.49 kilowatt-hour power consumed per ton clinker and assuming a monthly clinker production of 100,000 tons this would result in an additional 49,000 kilowatt-hour of power consumed.

4. Conclusions

The cumulative effect of heat efficiency losses and increases in power consumption resulting from kiln downtime are significant and this study allows this consumption to be isolated from production power requirements. The increasing kiln downtime hours experienced in the plant and the corresponding increasing impact of efficiency losses require such losses to be factored into an economic impact analysis of failure. This analysis will improve decision making in maintenance improvement activities.

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