Towards Waste Minimization in Wet Trades: Meteorological Based Model of Cement Demand in Port Harcourt Metropolis

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Abstract

Production systems strive to achieve zero-inventory as a mechanism of waste minimization, which requires that the demand and supply of products are synchronized in time and volume. The effects of weather condition on construction projects has implications for site productivity, and consequently the demand for building materials, particularly in wet trades where cement is the primary constituent. The study explores and spotlights the multi-dimensional influence of weather conditions on the consumption of cement induced by the supply/demand gap. Using multiple regression analysis, the study provides statistical evidence establishing causality between weather and the trend in the consumption of cement. Data on the consumption of cement on hundred randomly selected construction sites within Port Harcourt, as well as meteorological data for a period of 12 months, were collated to serve as quantifiable attributes of the study variables. The outcome of the study was the development of a regression model statistically depicting the demand for cement as a function of meteorological indices. The study outcome can thus serve as part of a more comprehensive decision support system, necessary to minimize waste and identify potential inefficiencies in the production and distribution channels of cement in Port Harcourt.

Keywords: Cement; Climate; Construction; Demand; Pollution; Supply; Waste Minimization.

Introduction

'Wet trades' is the general terminology used to group those works/trades in the construction industry, which are mostly wet in nature or require wet substances. These include works that require material mixture with water before application. Cement is a finely milled hydraulic mineral powder which serves as a binder and irreversibly hardens upon addition of water, due to its adhesive and cohesive properties (Amadi and Amadi, 2013). As a result, it is the basic ingredient in concrete, which is widely used in wet trades of building and civil engineering construction. Typically, cement mixed with fine aggregate and water produces mortar for block laying and plastering, while cement mixed with fine and coarse aggregate forms concrete (American Concrete Institute,1985). Cement can therefore be considered an essential commodity in wet trades.

Cement, the fundamental ingredient in concrete, is calcium silicate, made with a combination of calcium, silicon, aluminum and iron. The first step in the cement manufacturing process is obtaining raw materials. Generally, raw materials consisting of combinations of limestone, shells or chalk, shale, clay, sand or iron ore are mined from a quarry near the plant (Reding, *et al*., 2007).). At the quarry, raw materials are produced by primary and secondary crushers. Stone is first reduced to 5-inch size (125mm), then to ¾ inch (19mm). Once the raw materials arrive at the cement plant, the materials are proportioned to create cement with a specific chemical composition. Once the production of cement is complete, the finished product is transferred to large, storage silos, for onward transportation.

Concrete is the most widely used building material, due to its strength and durability (Parker, 2008). Particularly in the tropics, concrete is used in the construction of most civil and building projects. In Nigeria, ninety percent of all construction works are concrete based and as a result there is an over reliance on the use of cement (Amadi and Higham, 2017). Cement production in Nigeria is logically tied to the demand for construction. In terms of building works, the demand for cement is primarily driven by the demand for residential/non-residential construction. Due to population pressure in Nigeria, the demand for residential construction remains at an all-time high, while the demand for non-residential construction fluctuates in tune with the level of business activity which is mostly dictated by economic variables.

Although the demand for cement required for residential construction is high in Nigeria, wastage often occurs in the wet humid tropical setting of Port Harcourt city, due to difficulty in forecasting local consumption, in response to weather conditions. Evidently, most construction activities and processes, particularly those in wet trades, are sensitive to weather conditions (El-Rayes and Moselhi, 2001). Climatic conditions in Port Harcourt is typical of the humid tropics, is generally characterized by frequent and substantial torrential rains, occurring for six months of the year and beyond (Aisuebeogun,1995). Furthermore, weather conditions, whereby high humidity and temperatures prevail will also indirectly cause productivity decreases, due to biological strain (Bob Manuel, 2005). The implication of this climatic sequence, inherent in Port Harcourt is thus that site works are severely impacted, and consequently will determine productivity and material demand in time and volume. Weather conditions therefore logically dictate the usage or wastage of cement on construction sites at various times of the year.

A fundamental principle of production systems however, is the minimization of waste. Overproduction is a major source of wastage in the manufacturing sector. Koskela (1992) described such waste as either quantitative or anticipated, wherein waste from quantitative overproduction occurs due to the production of a higher quantity than programmed, while waste caused by anticipated overproduction is waste generated due to production before it is required. Matching supply to demand in time and volume is thus key to preventing waste due to over production (Fradinata et al., 2015). Unanticipated production waste occurs whereby supply of cement does not match demand at time of production, which will have waste generation implications. As a result, gauging the extent to which weather conditions triggers onsite productivity reduction continues to be a topical issue established in the literature as a fundamental requirement for enhanced productivity and by implication waste reduction (Anosike, 2011; Dytczak, 2013; Ballesteros-Perez, 2017a, b; Ballesteros-Perez et al., 2018). As Weslley and José (2015) reiterates, achieving efficiency in production systems, requires the identification of consumer requirements, elimination of non-value adding activities and organization of production as a continuous flow to ensure zero inventory.

Against this backdrop, the study posits that predicting market demand for cement, as influenced by weather conditions, is fundamental to projecting consumption/demand curves in Port Harcourt, necessary for systems improvement in production cycles (Uzzaman et al., 2016). This study is thus carried out to investigate the sensitivity of the demand for cement to variable weather conditions, relevant to eliminate waste from overproduction due to displaced time scales. The seasonal variability of combinations of meteorological variables thus represent useful input in the production and distribution of cement, which is the key material requirement in wet trades. The study explores the predictive capacity of meteorological variables as determinants of the level of construction activity in wet trades, and consequently the demand for cement in Port Harcourt. This is with a view to inform management decisions during cement production towards construction demand-oriented forecasting.

Weather patterns are determined by the variability of climatic elements such as rainfall, temperature, wind, vapour pressure/humidity over a region (Ballesteros-Perez, et al. (2018). These elements vary from place to place and at different times of the year, (Bob-manuel, 2005). Different combination of meteorological elements defines the immense variety of weather distributed over the earth and so a nomenclature of broad climatic types is often used. Weather pattern in Port Harcourt (the study area) is characteristic of the equatorial tropical climate. Temperatures are generally high and follow a very constant thermal pattern all year, with a range of average monthly temperature (1 – 3^0C) and a thermal range of about 8^0C. Maximum temperature centers about 38^0C. Humidity and rainfall are predominantly high for most of the year. The incidence of rain which is very regular, induces a slight temperature drop and are affected by trade winds may be accompanied by violent electric storms. The intensity of diffused and direct solar radiations varies widely with the cloud conditions and reflected radiation from the ground is usually low as vegetation is dense and the damp soil dark.

Weather impact is one of the greatest challenges to construction in Port Harcourt since the production process is entirely an outdoor process and thus exists to grapple with the issue of weather. Rainfall is the most vital climatic element which affects productivity in Port Harcourt, due to high level of recorded amount and lengthy duration (Aisuebeogun, 1995). No month is without the incidence of rainfall, with prolonged heavy downpours generally occurring during the rainy season months. This often leads to delays and loss of productive man hours. Nunnally, (2007) defined productivity as the ratio between output and input i.e. the amount produced against the amount of the resources used during production. It generally falls to the management of an enterprise to try to achieve the greatest productivity possible (Jang et al., 2008, 2016). Extremely wet weather is however deleterious to production activities as it leads to disruption of site activities and work stoppage (Lawson, 2009). The literature is consequently rife with numerous studies which have attempted to address weather related impacts on construction works. Typically, Thomas et al. (1999) analysed labor productivity losses due to weather; Thorpe, and Karan (2008.) developed a method to compute schedule delay arising from weather conditions; Marzouk and Hamdy (2013) quantified weather impact on the use of formwork for concrete works, El-Rayes and Moselhi (2001) developed a decision support system for quantifying the impact of rainfall on the productivity and duration of highway construction operations. Older studies (Cantwell 1987; Smith and Hancher 1989) have considered the impact of weather on work stoppage and established daily rainfall thresholds that would cause the stoppage and interruption of construction activities. Taking a cue from the rain patterns inherent in Port Harcourt (Figure 1), It can be observed that although the dry season lasts from November to March, it is usually characterized by occasional interruptions of sporadic downpours (Aisuebeogun, 1995). This period however represents the best period for carrying out operations in wet trades, particularly in January which appears to be the driest month with an average rainfall of 0.921mm. Other dry months are February and December with average rainfall of 1.140 and 1.29 respectively. The wet season lasts from April to October and virtually takes up about six months of the year, its effect being very severe. However, rainfall is still experienced in every month reaching a climax in the month of July. Some production sites may be rendered completely unproductive and inaccessible due to flooding and water logging of adjoining areas as rainfall value of 4300mm can be recorded. Records maintained by the Nigerian Meteorological Agency (NIMET) show that July has the highest rainfall. Other months with high recorded rainfall are June, August, September and October. Regular work stoppages and loss of productive man hours for such works as mixing and moulding are likely to be experienced.

As the literature evidences, climatic variables have multidimensional impact on productivity, mostly manifesting their impact on man energy level as well as on the quality of works produced (Thomas, et al.,1999; Al-Abbasi, 2014; Li et al., 2016). The measurement of climatic effects on the human body has been investigated in many ways (Ogunsote and Ogunsote, 2002). Some methods described the very effects of climate on man expressed as strain or pain, disease and death. Others define the conditions in which man's productivity, health, mental and physical energy are at the highest efficiency (Amadi, and Higham, 2016).

In Port Harcourt, temperatures are high throughout the year and the short construction season available which is the dry season, could record temperatures as high as 35^0C during the day with monthly average of about 32.2^0C during this season (Bob Manuel, 2005). Vapour pressure is exerted by a variable quantity of water vapour contained in the atmosphere. A pioneer study by Olgyay (1963) shows that people usually experience a close or depressed feeling, when vapour pressure surpasses the15mm mercury mark. In Port Harcourt, the vapour pressure and relative humidity is consistently high through-out the year affecting labour output and performance negatively (Amadi, and Higham, 2016). This recorded high temperature coupled with high relative humidity that can be as high as 80% or more, makes working condition under this climate quite uncomfortable. Winds/air movements are generally low, and the combined effect of these factors can pose acute physical stress on man's biological functioning and consequently productivity. As a result, one of the chief causes of thermal discomfort in Port Harcourt is the subjective feeling of skin wetness. This is because the wetness of the skin in any climatic setting depends on the ratio of the heat stress on the body to evaporative cooling capacity of the air, which in turn depends on the level of air movement, as air movements affect body cooling (Ogunsote and Ogunsote, 2002).

The harmattan which is a dust laden wind brings about a drop in relative humidity as the North-east trade which blows strongly across the country (Ayoade, 1988), Erroneously, however, it is believed that the harmattan has soothing effects on the sultry weather conditions. Bob Manuel (2005) calculated the Effective Temperature (ET) Index and wind chill index for the harmattan months and showed that the hamartin months are equally stressful and uncomfortable with no month having an ET of less than 27^0C.

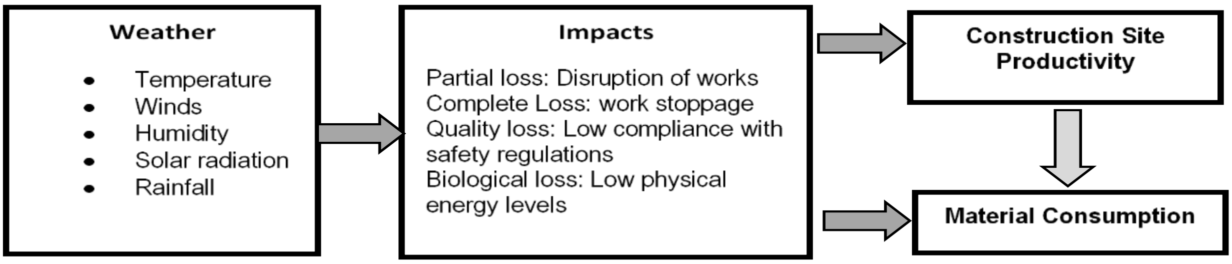

Figure 1: Conceptual Framework

As Figure 1 conceptualises, daily weather conditions in Port Harcourt will quantitatively influence the level of site productivity and material consumption. This is particularly in wet trades such as block laying, concreting, plastering etc, where complete losses may be experienced due to work stoppages, disruption of works, low energy levels or in compliance with safety regulations/quality requirements. Consequently, the study logically presupposes that the demand for cement is a function of the seasonality of meteorological variables.

Research Method

A sample of one-hundred randomly selected construction sites were visited within Port Harcourt City to obtain data on the quantity of cement used over a period of 12 calendar months. This data was collated from site stock records maintained on the sampled construction sites. Data on weather conditions for the 12-month duration was sourced from the Nigerian meteorological Agency (NIMET). Data was sourced on the duration of sunshine, rainfall amount and duration, vapour pressure and temperature. The bivariate data was collated to serve as quantifiable attributes of the study variables (Weather and Demand for cement). Secondary sources of data were therefore relied upon for the study. Data pre-processing and exploration via correlation analysis of the paired sample meteorological and consumption of cement data was carried to test for significant statistical association between meteorological variables and the demand for cement. Based on the outcome of the correlation analysis, significant relationships were determined. Regression analysis was further used to explain variation in the sales of cement relative to climate. Multiple regression analysis as opposed simple linear regression, which only shows the relationship between a dependent variable and just one explanatory variable was employed. The underlying logic being that multiple regression simultaneously captures the existing relationship between more than one explanatory variable and the dependent variable. The multiple regression analysis was carried out following several intermediary stages, whereby the model was fitted to test for collinearity and non-significant variables found where removed from the model, this is aimed at selecting variables that yield the highest R^2, while ensuring that outliers and covariance were simultaneously detected. The initial regression default model however started with all meteorological variables as determinants of the volume of sales for cement in Port Harcourt. The dependent variable (Sales) is denoted Y, while the independent meteorological variables are denoted X_1 to X_5, with the regression of Y on X expressed as:

$$Y=a + b_1X_1+b_2X_2+b_3X_3+b_4X_4 + b_5X_5 + e$$

Whereby X_1 = sunshine hours(S)
X_2 = temperature (T)
X_3 = humidity (H)
X_4 = rainfall amount (R)
X_5 = Number of Rainy Days (R_n)
e = error term

Results and discussion

Table 1: Data Set on Meteorological Variables Relative to Consumption of **Cement**

	Rainfall Amount (mm)	Rainfall duration (days)	Sunshine (hours/day)	Vapour Pressure (Mb)	Temperature (0^oC)	Consumption (Bags)
JANUARY	32.2	1	6	36	32.4	212674
FEBRUARY	66.5	7	6.5	37	33.4	202960
MARCH	126.3	14	6	38.5	32.6	213377
APRIL	219.6	13	6	39	32.1	170840
MAY	292.7	16	6	39	31.2	167395
JUNE	303.3	19	3.5	38.5	30	167550
JULY	396.9	18	3	37.5	28.8	154662
AUGUST	376.8	19	3	38	28.7	149771
SEPTEMBER	487.1	21	2.5	39	29.3	148620
OCTOBER	263.1	20	4	40	30.2	165035
NOVEMBER	106.9	13	6.5	37	31.3	17099
DECEMBER	30.9	3	7	35.7	31.8	20023

Table 1 shows a match of the relationship between meteorological variables and the amount of cement sold, based on this result, it is observed that between January –March, where rainfalls are reduced and temperatures high, the sales of cement was higher ranging from 202,960 bags of cement to

213377 bags of cements, while from December, where rainfalls begins and grows higher and more frequent, sales of cement fell from 20023 to 148620 in September, the trend of demand and use of cement is higher in the short dryer seasons than during the wet seasons.

From the output of the correlation analysis in Table 2, rainfall duration, rainfall amount and sunshine hours and display shows significantly high correlations with the consumption of cement. Temperature, however displayed a weaker correlation with the consumption of cement, while vapour pressure was returned as statistically insignificant in accounting for the demand for cement.

Table 2: Correlation of Meteorological Variables versus Cement Consumption

		Consumption
Rainfall Amount	Pearson Correlation	-.830
	Significance	.002
Rainfall duration	Pearson Correlation	-.930
	Significance	.002
Average Temperature	Pearson Correlation	.625
	Significance	.00
Sunshine hours	Pearson Correlation	.716
	Significance	.000
Vapour pressure	Pearson Correlation	-.447
	Significance	.418

A positive correlation coefficient returned from the correlation analysis for sunshine hours implying the consumption of cement increases with longer duration of sunshine. However, rainfall duration and rainfall amount display a negative correlation with cement consumption pattern, implying that the consumption of cement decreases with longer duration of rainfall and increase in amount with shorter rainfall durations. The highest degree of association (-0.930) was observed for Rainfall duration, which implies that the number of rainy days is the most influential meteorological factor affecting the consumption pattern of cement in Port Harcourt. This result varies from previous studies, such as those by Al-Abbasi (2014) which reported temperature as having the strongest impact on wet trade productivities. However, the study findings report similar lower correlations for wind and vapour, further reinforcing that wind and vapour have minimal impact on wet trade productivities

Tables 3 and 4 are the output of the default variable selection in SPSS, which eliminated vapour pressure, similar to the outcome of the correlation analysis.

Table 3: Variables Entered/Removed

	Variables Entered	Variables Removed	Method
1	, Rainfall amount, Rainfall Duration, Sunshine hours, Temperature	Vapour Pressure.	Enter

a. Dependent Variable: Cement Consumption

Table 4: Tolerance of Variable Removed

	Collinearity Statistics		
	Tolerance	VIF	Minimum Tolerance
Vapour Pressure	.000	.	.000

Table 5 highlights significant bi-variate correlations between the meteorological variables.

Table 5: Correlation Matrix of Meteorological Variables

		Ra	Rn	Sh	Ta
Ra	Pearson Correlation	1	**0.970****	.063	.052
	Sig. (2-tailed)		.000	.627	.691
Rn	Pearson Correlation	**0.970****	1	.063	.052
	Sig. (2-tailed)	.000		.627	.691
Sh	Pearson Correlation	.-054	-.063	1	.089
	Sig. (2-tailed)	.627	.627		.494
Ta	Pearson Correlation	.052	.052	.089	1
	Sig. (2-tailed)	.691	.691	.494	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Therefore, despite the relatively high correlations between the consumption of cement and both rainfall amount and number of rainy days, one of the two variables must be deleted from the final model to eliminate collinearity effects. A regression cost model was thus reduced to incorporate lesser number of variables, to maximize its explanatory power. Based on the correlation matrix outputs therefore, two regression models, representing the likely combinations of input variables were run in the following combinations, to test for the combination that yielded the highest variance in cement usage (R^2): Rn, Sh, and Ta; Ra, Sh, and Ta. The outcome of the regressions run with the two sets of meteorological variables is shown in Table 6 a and b, with explained variances highlighted.

Table 6a and b: Alternative Regression Models after Collinearity Diagnostic

Model Summary

Model	R	**R Square**	Adjusted R Square	Std. Error of the Estimate
1	.827[a]	**.683**	.598	.73907

a. Predictors: (Constant), Rn, Sh, and Ta

Model Summary

Model	R	**R Square**	Adjusted R Square	Std. Error of the Estimate
1	.754[a]	**.570**	.542	.73532

a. Predictors: (Constant), Ra, Sh, and Ta

As Table 6a and b shows, model-a with input predictors: Rn, Sh, and Ta, which explained about 68.3% of the variation in the consumption of cement optimises the variance. This is relative to model-b, generated with input predictors: Ra, Sh, and Ta, which explained 57% of the variation. Tables 7 and 8 shows that the exclusion of collinearity effects has improved the models explanatory capacity from 0.36, for the unfitted initial model for four variables: Ra, Rn, Sh, and Ta, to 0.683, based on three variables: Rn, Sh, and Ta.

Table 7: Initial Regression Model

Model	R	**R Square**	Adjusted R Square	Std. Error of the Estimate
1	.600[a]	**.360**	.344	352.14661

Predictors: (Constant), Ra, Rn, Sh, and Ta

Predictors: (Constant), Rn, Sh, and Ta

Table 8: Final Regression Model

Selected optimal Model Summary

Model	R	**R Square**	Adjusted R Square	Std. Error of the Estimate
2	.827[a]	**.683**	.598	.73907

The ANOVA analysis returned in Table 9 for the final model also shows the significance of the model.

Table 9: ANOVA [a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	7.098	3	2.366	4.380	.008[b]
	Residual	29.170	54	.540		
	Total	36.268	57			

a. Dependent Variable: Cement Consumption
b. Predictors: (Constant), Rn, Sh, and Ta

The model coefficients for the fitted initial model are presented in Table 10

Table 10: Regression Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	80.167	1.041		5.402	.000			
	Sh	.035	.014	.448	-3.557	.001	.160	.136	-.134
	Ta	.013	.005	.063	.265	.796	.045	.035	.032
	Rn	-.660	.571	-.176	-.981	.331	-.583	-.432	-.420

a. Dependent Variable: Cement Consumption

The optimal regression meteorological based model of Cement Consumption is:

Cement Consumption = 80.167 + 0.035Sh + 0,013Ta – 0.660Rn + e ....*Equation 1*

The final model (Equation 1) represents the consumption of cement as a function of the number of Sunshine hours, Average temperature and number of rainy days. These thus represent the key meteorological variables which exhibit significant cause effect relationship with the seasonality of cement demand, and by implication productivity in wet trades. Wind and vapour pressure thus appear not to have significant bearing on the demand for cement in Port Harcourt.

Conclusion

The study has spotlighted the multi-dimensional influence of weather conditions on productivity on construction sites, and its implications for activities in wet trades. Specific meteorological variables: rainfall duration and rainfall amount and temperatures have been shown to displays negative correlations with cement consumption pattern, implying that the consumption of cement decreases with longer duration and amount of rainfall, but increases with increased temperature. Positive associations were however returned for temperature and number of sunshine hours, while vapour pressure was returned as statistically insignificant in accounting for cement consumption in Port Harcourt. Overall, rainfall duration, was statistically shown to be the most influential meteorological factor affecting the consumption pattern of cement, which was reflected in the outcome of the regression analysis.

However, it must be recognized that the consumption of cement in port Harcourt will be influenced by other variables such as macro and micro-economic variables as well as geographic factors, which will affect the statistical validity of the analysis output. This study is thus exploratory in nature, as such the model is not validated. The study outcome however provides useful indication that meteorological variables constitute primary variables necessary for the synchronization of cement production forecasts with consumption in wet trades. This creates a platform for further studies, designed to improve the predictive capacity of the model via the incorporation of a broader range of input variables. Nonetheless, irrespective of the limitations acknowledged, the results had explained to some degree, the seasonal differences in the monthly consumption of cement in Port Harcourt, which can form part of a decision support system for forecasting cement demand.

The development of a comprehensive regression model, relevant to identify monthly consumption patterns, will have far reaching implications. The quantification of weather impact on construction activities and consequently demand for materials, is clearly valuable to the entrepreneurial function of management in the distribution and sales channels of cement production in Port Harcourt, due to the adversity of climatic conditions. Organization of the production and distribution of cement as a continuous flow to ensure zero inventory also requires that weather conditions in Port Harcourt be incorporated in the projection of production forecast, necessary for the just in time delivery of cement, without maintaining intermediate stock. This will serve to minimize wastage and identify potential inefficiencies in the production and distribution channels of cement in Port Harcourt. The study submits that predicting market demand for cement, hinged on the variability of weather conditions, is fundamental to projecting consumption/demand curves in Port Harcourt, necessary for systems improvement in production cycles.

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