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Development of a Time-Cost Model for Construction Projects in Rivers State University, Nigeria

Kenneth Miebaka Oba[1] and Kelechukwu Dimkpa[2]
[1]Department of Civil Engineering, Rivers State University, Port Harcourt, NIGERIA
[2]Department of Architecture, Rivers State University, Port Harcourt, NIGERIA

[1]Corresponding Author: kenneth.oba@ust.edu.ng

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ABSTRACT

This study aimed to develop a mathematical model to address the problems of construction costs and delays in buildings owned by tertiary institutions in Nigeria. A total of eleven building construction projects awarded and executed at Rivers State University between 2016 and 2023 were studied. Bromilow's Time-Cost (BTC) model, a non-linear power regression mathematical model was developed. The study showed that 1916.3 working days are required to complete a building construction in the Rivers State University, Nigerian, for every Aus$1 million. The model predictions resulted in R2 value of 0.7465 which was subjected to two-tailed student t-tests for the for the construction times and costs. The statistical results indicate that the model is fit and adequate. The study also proved that the BTC model is applicable in Nigerian tertiary institutions, especially Rivers State University.

Keywords—Bromilow, Buildings, Cost Overrun, Delays, Port Harcourt, Tertiary Institutions, Time-Cost Model

I. INTRODUCTION

It is now a general belief that time, cost, and quality are the most significant key performance indicators (KPI) for construction projects. The cost and time, in most cases, are more critical [1], [2], [3]. In line with that, [4], [5], [6] have been conducted on the cost, quality, and time as KPIs of construction projects in Nigeria, all in a bid to address the problems of delays and cost overruns in construction projects.

The city of Port Harcourt is a major place where oil and gas activities take place in Nigeria. It is the capital city of Rivers State, in the Niger Delta region of Nigeria, by the shores of the Atlantic Ocean. It is one of the highest revenue-generating cities in Nigeria. The city has a vast social and cultural heritage. It is also the home of notable establishments such as the headquarters of the Nigerian Liquified Natural Gas (NLNG), the Shell Petroleum Development Company (SPDC), the prestigious Rivers State University, and a lot of other industries, parastatals, public and private establishments. This is the major reason why investors, students, workers, and other business owners around the world are attracted to the city of Port Harcourt.

The Rivers State University, Port Harcourt, was established in 1980 to enable training and award of degrees to persons with excellence and creativity that will join the global competitive workforce. It was formerly called Rivers State University of Science and Technology but later assumed its current name in the year 2015. The university eventually began to admit an extremely large number of students due to its commencement of new programmes. This called for more faculty buildings, lecture halls, research outlets, and other larger and state-of-the-art facilities to match its world-class status. On this note, the new buildings have some problems bordering on delays and cost overruns.

Some factors affecting delays and cost overruns in construction projects in Nigeria include procurement methods, cash flow from the clients, inflation, budgeting, favouritism, weather, and nepotism. [7] recently studied time and cost for building construction projects in the city of Port Harcourt. There is however limited research on quality, time, and cost performances related to construction in tertiary institutions in Nigeria. A recent study by [8] was still not enough to make up for sufficient literature in the subject matter. This research is aimed at solving the problem of delays and cost overruns in the construction of buildings in tertiary institutions, by arming the construction researcher with a model that can predict completion times and construction costs while supporting [8]. The Bromilow's Time-Cost (BTC) model was also adopted for this study.

The study of delays and cost overruns in construction projects has faced different perspectives, with many resulting in mathematical modelling. Most of them were regression models. [9] carried out the first-ever research on construction performance in terms of mathematical modelling of time and cost. He performed the study on 303 building projects constructed to completion in Australia between the years 1964 and 1967.

The study resulted in the development of a non-linear power regression model as shown in eq. (1), which is now globally recognized as the Bromilow's Time-Cost model (BTC). That same study gave birth to the curve in Fig. 1

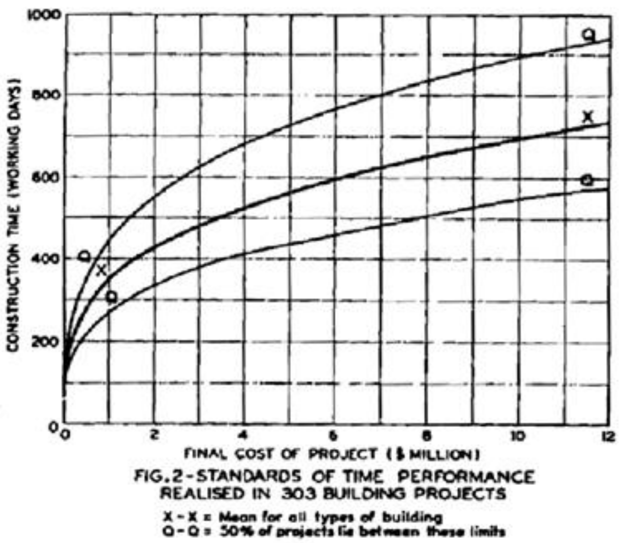

Figure 1: Project Cost vs Construction Time [9]

$$\boldsymbol{T = KC^B} \quad (1)$$

Where T = the time of the project in working days

C = the Cost of the project per million Aus$, adjusted to constant labour and material prices

K = a constant of the project time performance

B = a constant of the sensitivity of the time performance to cost level.

During the regression analysis, [9] derived K and B as 211 and 0.3 respectively. Since then, other similar studies have been conducted to derive K and B values as presented in Table 1. According to [9] the project time or duration has a high correlation with the size of the project with respect to cost. Others [5], [7], [8], [10], [11], [12], [13], [14], [15], [16], [17] have also upheld this fact. However, there have been huge criticisms from some researchers of the BTC model from different perspectives. Some [10], [11] argued that 'ln K' in eq. (3) has little or no predictive ability when the BTC model is linearized, hence should not be included in the model.

$$ln\,\mathrm{T} = ln(\mathrm{KC^B}) \quad (2)$$

$$ln\,\mathrm{T} = ln\,\mathrm{K} + ln\mathrm{C^B}$$

$$ln\,\mathrm{T} = ln\,\mathrm{K} + \mathrm{B}ln\mathrm{C} \quad (3)$$

On this note, [10], [11] modified the model to eq. (4) as follows:

$$\mathrm{B} = \frac{ln\mathrm{T}}{ln\mathrm{C}} \quad (4)$$

I y, [10] also discovered that there was no significant difference between buildings in the private and public sectors. For this reason, they derived a model for non-industrial buildings (which also includes educational and residential buildings) and a second model for industrial buildings using the BTC technique. Similarly, [13] proved that the BTC model does not apply to Ghanaian building construction projects as indicated by its weak R^2 values of 0.684, 0.463, 0.399, and 0.378 for buildings of office, classroom, residential, and combined data respectively. In another study, [15] posits that the BTC model does not apply to buildings in Nigeria, due to the model's weak R^2 value of 0.205. They then suggested the use of piecewise model, which resulted in R^2 of 0.765. Similarly, [5] found that the BTC model was not applicable in Nigerian road construction projects, as it results in a weak predictive ability, having a Mean Absolute Percentage Error (MAPE) of 19%, and an R^2 of 0.549. However, [12] upheld the different dimensions of the calibration of the BTC model, insisting that, although the criticisms from [10], [11] were based on Australian data, but were not consistent with literature and their studies. In a similar light, [14] also confirmed that the BTC model applies to residential buildings in Slovakia, as they obtained an R^2 of 0.808 and a MAPE of 12.3%. These are indications of a strong predictive capability and ability. [7] recently also confirmed the strong applicability of the BTC model when applied to residential buildings in Port Harcourt, a major city in Nigeria.

Table 1: Values of B and K and B from different researchers

Researcher	Country	Sector of construction	Type	Model	K	B
[9]	Australia	Public	Building	$T = 211C^{0.3}$	211	0.3
		Private	Building	$T = 156C^{0.3}$	156	0.3
		Overall	Building	$T = 177C^{0.3}$	177	0.3
[10]	Australia	Public	Building	$T = 129C^{0.32}$	129	0.32
		Private	Building	$T = 132C^{0.3}$	132	0.3
		Overall	Building	$T = 131C^{0.31}$	131	0.31
[17]	Vietnam	Public	Building	$T = 98.1C^{0.343}$	98.1	0.343
		Private	Building	$T = 87.2C^{0.348}$	87.2	0.348
		Overall	Building	$T = 93.6C^{0.338}$	93.6	0.338
[5]	Nigeria	Public	Highway	$T = 2.8C^{0.5352}$	2.8	0.5352
[13]	Ghana	Office	Building	$T = 344.586C^{0.684}$	344.586	0.684
		Residential	Building	$T = 512.28C^{0.463}$	512.28	0.463
		Classroom	Building	$T = 2.807C^{0.399}$	2.807	0.399
		Combined	Building	$T = 3.17C^{0.378}$	3.17	0.378
[16]	Poland	Public	Highway	$T = 3.342C^{0.4649}$	3.342	0.4649
[15]	Nigeria	Private	Building	$T = 63C^{0.262}$	63	0.262
[7]	Nigeria	Private	Building	$T = 2289.2C^{0.624}$	22289.2	0.624
[8]	Nigeria	Public	Building	$T = 1858.3.2C^{0.482}$	11858.3	0.482

Since the year 1969 when the first time-cost model was derived by Bromilow, many other mathematical models have been derived and put to effective use. Some of them used the BTC technique, while others did not [17], [18], [19], [20], [21], [22]. It was shown by [16] that the linearized form of the BTC in eq. (3) is the most efficient for the Polish construction industry, while comparing it with two other time-cost models. Research on sustainable and conventional university buildings in North America, was recently conducted by [19] with the aid of a multiple linear regression (MLR) model. They arrived at an R^2 value of 0.874. This showed that their model was fit and adequate. Their t- and F-tests proved that there was no significant difference between the actual and predicted construction costs. In a similarly study by [23], the construction cost of communication towers in Iraq was predicted, using the MLR model. The results of the R^2 and MAPE were 0.984 and 9.891% respectively. These were strong indications that their model was fit. [20] also developed a number of models using different mathematical modelling techniques. Their findings indicate that the MLR with R^2 of 0.9944 was better than the Artificial Neural Network (ANN), Trend line, and Factor based models whose values were 0.9090, 0.9694, and 0.8614 respectively. However, another study by [24] affirmed that the Support Vector Machine (SVM) model gave more accurate predictions than the BTC and MLR models.

II. METHODOLOGY

This research was carried out by collection of data comprising building construction projects executed by the physical planning unit of the Rivers State University. The data cuts across projects that commenced between the years 2016 and 2022. The said projects were completed between the years 2018 and 2023, amounting to eleven in number. From eq. (1), the BTC model for this study was formulated, calibrated, and developed. The model was used to predict the cost and time for each project. With the use of two-tailed t-tests, the predicted costs and times were statistically tested.

III. RESULTS AND DISCUSSIONS

Table 2 shows the costs and times (durations) to complete each of the eleven projects.

Table 1: Construction Costs and Completion Times for each Project

S/N	TITLE OF PROJECT	APPROVED COSTS (₦)	COSTS (Aus$1,000,000)	DURATIONS (DAYS)
1	CONSTRUCTION OF INSTITUTION OF POLLUTION STUDIES BUILDING	41,168,062.50	0.0448078	65
2	CONSTRUCTION OF QUANTITY SURVEYING BLOCK COMPLEX	175,301,982.33	0.190800725	788
3	CONSTRUCTION OF HOSTEL BLOCK COMPLEX 1	215,097,493.60	0.234114625	876
4	CONSTRUCTION OF HOSTEL BLOCK COMPLEX 2	220,000,000.00	0.23945057	922
5	CONSTRUCTION OF CENTRE FOR CONTINUING EDUCATION BUILDING	686,152,684.88	0.746816597	1231
6	CONSTRUCTION OF ENTREPRENEURSHIP CENTRE	176,741,502.05	0.192367515	711
7	CONSTRUCTION OF DEPARTMENT OF ANATOMY AND PHYSIOLOGY BUILDING	279,810,440.26	0.304548952	943
8	CONSTRUCTION OF FACULTY OF SOCIAL SCIENCE BUILDING	924,485,419.87	1.00622073	1376
9	CONSTRUCTION OF FACULTY OF EDUCATION BUILDING	923,576,595.11	1.005231554	1250
10	CONSTRUCTION OF LECTURE THEATRE BUILDING	196,673,099.25	0.214061299	500
11	CONSTRUCTION OF LECTURE HALL BUILDING	228,996,086.13	0.249242015	655

The data form Table 2 was used to develop the BTC model for building construction projects in the Rivers State University, Port Harcourt. Microsoft Excel was used, as this is presented in eq. (5) and in Fig. 2. ₦918.77 was the exchange rate of Aus$1 as of February 2024.

$$T = 1916.3C^{0.811} \tag{5}$$

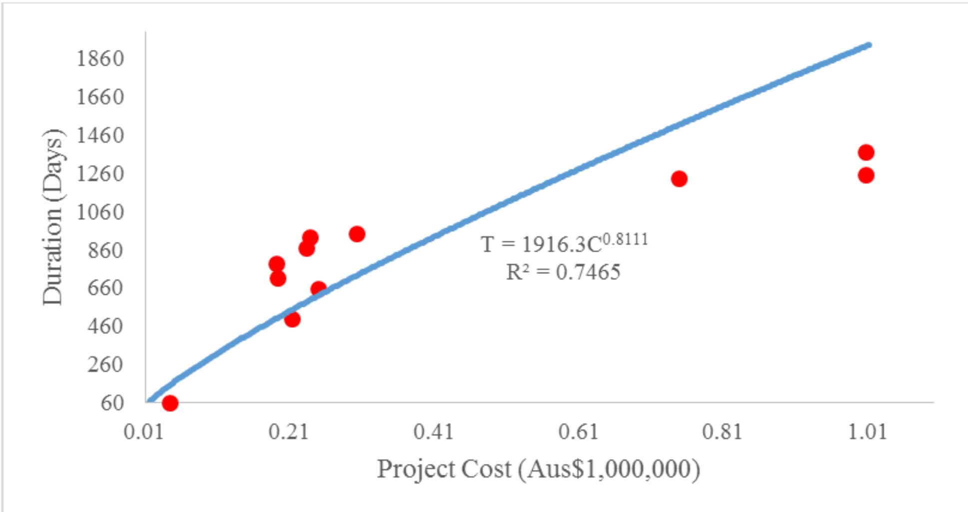

Figure 2: The BTC model for building Construction Projects in the Rivers State University

The R^2 turned out to be 0.7465. Table 3 shows the predicted results.

Table 2: Predicted Times and Costs of Building Projects

S/N	TITLE OF PROJECT	ACTUAL COSTS (Aus$1,000,000)	PREDICTED COSTS (Aus$1,000,000)	ACTUAL DURATIONS (DAYS)	PREDICTED DURATIONS (DAYS)
1	CONSTRUCTION OF INSTITUTION OF POLLUTION STUDIES BUILDING	0.0448078	0.015	65	154
2	CONSTRUCTION OF QUANTITY SURVEYING BLOCK COMPLEX	0.190800725	0.334	788	500
3	CONSTRUCTION OF HOSTEL BLOCK COMPLEX 1	0.234114625	0.381	876	590
4	CONSTRUCTION OF HOSTEL BLOCK COMPLEX 2	0.23945057	0.406	922	601
5	CONSTRUCTION OF CENTRE FOR CONTINUING EDUCATION BUILDING	0.746816597	0.579	1231	1512
6	CONSTRUCTION OF ENTREPRENEURSHIP CENTRE	0.192367515	0.295	711	503
7	CONSTRUCTION OF DEPARTMENT OF ANATOMY AND PHYSIOLOGY BUILDING	0.304548952	0.417	943	731
8	CONSTRUCTION OF FACULTY OF SOCIAL SCIENCE BUILDING	1.00622073	0.665	1376	1926

9	CONSTRUCTION OF FACULTY OF EDUCATION BUILDING	1.005231554	0.591	1250	1924
10	CONSTRUCTION OF LECTURE THEATRE BUILDING	0.214061299	0.191	500	549
11	CONSTRUCTION OF LECTURE HALL BUILDING	0.249242015	0.266	655	621

In Table 4, the two-tailed student t-test results, as well as the R^2 values for the times and costs are presented. The results indicate that the model is adequate and fit.

Table 3: Details of Costs and Durations of Building Projects

t-Test: Paired Two Sample for Means			t-Test: Paired Two Sample for Means		
	T_{actual}	$T_{predicted}$		C_{actual}	$C_{predicted}$
Mean	847	873.8168	Mean	0.402515	0.376356
Variance	139616.2	375791.7	Variance	0.118676	0.035814
Observations	11	11	Observations	11	11
Hypothesized Mean Difference	0		Hypothesized Mean Difference	0	
df	10		df	10	
t Stat	-0.25719		t Stat	0.431795	
P(T<=t) one-tail	0.401124		P(T<=t) one-tail	0.337526	
t Critical one-tail	1.812461		t Critical one-tail	1.812461	
P(T<=t) two-tail	0.802249		P(T<=t) two-tail	0.675052	
t Critical two-tail	2.228139		t Critical two-tail	2.228139	
Correlation	R^2	R^2 (adj.)	Correlation	R^2	R^2 (adj.)
	0.7465	0.7184		0.7660	0.7400

IV. CONCLUSION

The data obtained from the physical planning unit of the Rivers State University, Port Harcourt, for building construction projects awarded and completed between the years 2016 and 2023 were analysed and used to formulate a Power equation in line with the BTC approach. From the findings of the research, it requires 1916.3 working days to complete the construction of a public building in the Rivers State University, Port Harcourt, for each Aus$1 million. This is greater than most of the results from the findings of other similar studies. However, the result is similar to that of [8], indicating affirmation of all the findings of that study. However, the model derived from this study was confirmed adequate and fit, having passed the student t-test, and having an R^2 of 74.65%. The study has therefore proven [5] and [15] wrong, as it has shown to be very much applicable in the Nigerian construction industry. This can also be so for tertiary buildings, especially those in the Rivers State University, Port Harcourt. The problems of delays in construction time, and cost overrun in the construction of buildings have been addressed with the formulated BTC model. Recommendations are hereby made for further studies to improve on the applicability of the model and to expand it to cover other areas in the construction industry of Nigerian.

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