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APPLICATION OF BROWMILOW'S TIME-COST (BTC) MODEL TO HIGHWAY PROJECTS IN NIGERIA

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Abstract

Practitioners and researchers have long recognised the significance of time and cost of construction as crucial to project feasibility assessment and budget allocation decisions. Therefore it is imperative for clients and contractors to obtain reliable and accurate estimates of both time and cost at the planning phase of a project. This study examined the application of Browmilow's Time-Cost (BTC) model for the prediction of highway construction time in Nigeria using a set of completed projects database. Linear regression was performed to investigate time-cost relationship of the data. The result revealed a positive correlation between the variables with R and R^2 values of 0.734 and 0.549 respectively. A log-log regression in the form of the BTC model was developed to determine the value of K which showed general level of time performance and β which demonstrated the sensitivity of time performance as affected by project size measured by cost. The result indicated a K value of 2.8 which is very low compared to values obtained in previous studies for other categories of construction. The β value of 0.53 indicates a greater influence of project complexity on the prolongation of time of construction. The model demonstrated a good fit to the data with R value of 0.736 and R^2 value of 0.542. The model also showed a weak prediction efficacy with a Mean Absolute Percent Error (MAPE) of 19% over a test sample which is considered inadequate for application in practice. The potential limitation of the model is that it does not consider other factors apart from cost that have effect on construction time.

Keywords: Browmilow's time-cost (BTC) model, project planning, highway, Nigeria

1. Introduction

Sponsors of capital projects require reliable and accurate estimate of construction time at the early project stage as a result, realistic project duration needs to be incorporated in the bid package. This is essential because most construction projects around the world are procured on the basis of time and cost (Benette and Grile, 1990; Lowe and Skitmore, 1994 and Durson and Stoy, 2011). Reliable estimates of time and cost at the early project phase are crucial for feasibility analysis and budget allocation decisions and they often become the basis upon which future estimates are judged. Practitioners and researchers have long recognised the significance of these variables for determining the success and viability of projects (Bowen *et al*. 2000; Chan and Chan, 2003; Ogunsemi and Jagboro, 2006). Project completion time is often used as an indicator of contractor's, efficiency, professionalism and competence which reflects the ability of a contractor to organize and control site operation, appropriately allocate resources and manage the flow of information to and from the design team and among all other parties (CIDA, 1993).

Construction time and delay has been a major concern to all stakeholders in the construction industry around the world because contract time overrun is a common problem that increases contractor's costs thereby reducing profit margin and reputation (Ng *et al.* 2001). Mbachu and Olaoye (1999) earlier reported that one factor that is aggravating the Nigerian construction industry is that almost all projects are realized at duration much longer than initially planned. This was corroborated by the study of Olupopola *et al*. (2010) which revealed that projects in the Nigerian construction industry are completed beyond their initial

estimates and evident from the study of Odunsami and Olusanya (2000) who reported that construction projects in Lagos metropolis experience about 51% delay. The observations may be attributed to the numerous factors affecting time performance, and the complex nature of construction projects which brings into play the services of many professionals to realize such projects.
In Nigeria, construction projects are rarely fulfilled in accordance with their initial estimated duration due largely to factors associated with construction time. In view of this it is imperative to develop a robust model for predicting time duration of construction projects. Mak *et al.* (2000) observed that the existing heuristic-based estimation of construction time has been considered as inefficient and could result in disparity between the actual construction time and the contract duration.

1.1 Time-Cost Relationship

Time and cost are important success factors increasingly being used as a benchmark for evaluating project performance. The relationship between time and cost of construction was first established by Bromilow (1969). Bromilow (1969) indicated that the time taken to construct a project is highly correlated with the size of the project measured by cost. He established that construction time in working days (T) could be expressed as a function of million dollars (C) based on the regression line of fit and upper and lower quartile limits derived from the historical data on construction time performance (CTP) within the construction industry. In general, the more resources are allocated to an activity, the less time it will take to complete the activity, but usually the cost is higher. This trade-off between cost and time presents a serious challenge and opportunity for practitioners and researchers to work out the best construction plan that optimize time and cost to complete a project. The two types of cost associated with construction project are the direct and indirect costs which increase with increase in project duration. Labour cost is an example of the direct cost, while administrative, overhead, depreciation and insurance costs are examples of indirect cost. Indirect costs are highly dependent on the duration of the project, thus a faster project is often a less expensive one (Magrebhi, *et al.* 2013). Therefore the task before project management as opined by Gupta, (2008) is the determination of the optimum duration with minimum cost. Moreover, determining the optimum trade-off between cost and time is one of the most challenging aspects of project management. Reducing the duration of a project is accomplished by reducing the duration of some of its constituent activities. This typically would involve increase in resources such as technology, level of competency of crews, equipment and working hours assigned to those activities. On one hand, increasing the resources will increase the direct cost of the activities and save project time with reduction in indirect cost of the project, on the other hand. The relationship between project time and cost is illustrated in Figure 1.

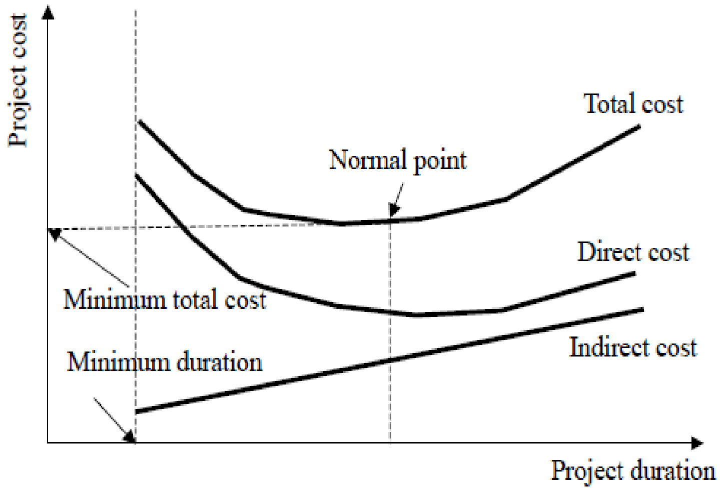

Figure 1: Project time and cost relationship

Several methods exist for compressing the construction schedule, some common methods include overtime, shifting, increasing crews and using more productive equipment. However regardless of the method used, the schedule compression will cost more than normal (Magrebhi *et al.* 2013).

1.2 Duration Predicting Models

The main thrust of duration predictive models is to provide fast, accurate and precise prediction of construction duration. The two common methods for the estimation of project completion time are either based on clients time constraints or through a detailed analysis of work to be done and resources available using estimates of time requirements for each specific activity. Predictive models for efficient, fast and accurate estimating of construction duration are developed based on database of completed projects which are usually prepared by construction professionals for use in developing new models or improving on existing ones. Development and improvement of construction duration models has been the subject of many studies (Bromilow 1969; Izam and Bustani, 1999; Ogusemi and Jagboro, 2006, Waziri, 2012; Maghrebi, 2013).

In view of the variability and uncertainties that are involved with time, construction time performance is regarded as statistical in nature. The first empirical modelling of CTP was carried out in Australia by Bromilow (1969) and the outcome is referred to as the BTC model which enables construction duration to be calculated based on the estimated final cost of the project.

A relationship between construction cost and the time taken to complete a construction project was first mathematically established by Bromilow (1969) and subsequently updated by Bromilow *et al.* (1980). The equation describing the relationship can be stated as:

$$T = K \times C^{\beta} \quad (1)$$

where: T = duration of construction period from the date of possession of site to substantial completion in days.

C = completed cost of project in millions of Australian dollars adjusted to constant labour and material prices.

K = a constant indicating the general level of time performance per million Australian dollars and

β = a constant describing how the time performance is affected by the size of the construction projects measured by the cost.

Following the BTC model several studies have been undertaken to validate, improve or replicate the model for other categories of construction projects. Ireland (1986) replicated the study to predict construction time of high rise building in Australia. Kaka and Price (1991) examined the relationship of buildings and road projects in the United Kingdom. Kumaraswamy and Chan (1995) examined the time-cost relationship of buildings in Hong Kong. Chan (1999) conducted similar research of building projects in Malaysia. Ng *et al.* (2001) tested the BTC model and refitted it with a new set of data for Australian construction projects completed between 1991 and 1998. The result of the study indicated an improvement in construction speed over the period but the alteration made to the log-log model failed to produce any improved fit. The BTC model was replicated by Choudhury and Rajan (2003) using 55 residential building project data in Texas. The result of the study indicated that the BTC model holds a good prediction for the Texas construction industry at the level of significance (p value) < 0.0001. All these studies revealed that the mathematical model presented by Bromilow *et al.* (1969) holds good for the prediction of construction time if the cost of construction is known. Ogunsemi and Jagboro (2006) developed a time-cost relationship of construction projects in Nigeria using 87 completed projects based on the concept of the BTC model. The result of the study produced a model $T = 63C^{0.262}$ with a poor predictive ability for both private and public projects with R and R^2 values of 0.453 and 0.205 respectively. In furtherance of this, they developed piecewise regression models for the prediction of the Time duration of construction projects. Waziri (2012) developed a mathematical model in the form of BTC for the prediction of construction time using a data set of sixty completed institutional building projects in North Eastern Nigeria. The model showed a good fit to the data with R value of 0.845 and R^2 value of 0.716. The model also showed a satisfactory prediction performance with mean absolute percentage error (MAPE) of 13.6% over a test sample.

This study therefore attempts to develop a pragmatic mathematical Time-Cost relationship for predicting durations of highway projects in Nigeria that would be useful to both clients and contractors for determining realistic construction duration at the early project phase.

2. Methodology

The data for the analysis was obtained from the records of thirty two (32) completed highway project data in Gombe and Bauchi States, Nigeria. The data were limited to projects initiated and completed between 2008 and 2012 on the premise that the period experienced the same economic climate which is a key factor influencing cost and time overrun of construction projects. Highway projects that made up the survey population were restricted to those with contract value of more than ₦100,000,000 because projects with contract value less than ₦100,000,000 were considered to have limited scope and complexity. The average duration of construction of the data was 153 days while shortest and the longest durations were 78 and 252 days respectively. The highest contract sum of the project was ₦530,837,240 while the smallest is ₦100,751,000. The data was used to validate the log-log model developed by Bromilow (1969) for highway projects in order to apply it to Nigeria. The BTC model is of the form

$$T = KC^B \qquad (ii)$$

(2) The non linear model is clearly linear in the log-log form shown in Equation (3):

$$lnT = lnK + BlnC \qquad (iii)$$

(3)

$$Letting\ Y = lnT, x = lnC, \alpha_0 = lnK\ and\ \alpha_1 = B$$

Using the number of days (T) and millions of Naira spent on the project (C), the linear model was fitted to the data and the required K and β values being exp (α_0) and (α_1) respectively.

3. Results and Discussion

The time and cost data of the thirty two highway projects extracted from different contract documents used for the analysis is presented in Table 1.

3.1 Linear Relationship of Data

The Linear Relationship between time and cost was examined using regression analysis of the historical cost and time data. The result of the linear relationship indicates that the construction cost is positively related to the project duration with R^2 value of 0.5639 and R value of 0.7509 at $p< 0.0001$. The summary of the linear regression is presented in Table 2.

Table 1: Time and Cost Data of Highway Projects

S/No	Total Cost (₦'000,000)	Duration (Days)	Ln (Time)	Ln (Cost)
1	424.945	252	4.430817	6.05196
2	358.297	210	4.248495	5.881362
3	256.382	180	4.094345	5.546669
4	277.747	180	4.094345	5.626711
5	180.021	93	3.433987	5.193074
6	206.648	180	4.094345	5.331017
7	530.837	234	4.356709	6.274455
8	131.628	135	3.806662	4.87998
9	165.198	135	3.806662	5.107145
10	100.757	78	3.258097	4.572203
11	110.336	93	3.433987	4.70353
12	122.056	135	3.806662	4.80448
13	199.323	144	3.871201	5.294927
14	138.419	186	4.127134	4.930285
15	166.103	90	3.401197	5.112608
16	380.498	180	4.094345	5.941481
17	119.349	90	3.401197	4.782052
18	192.249	120	3.688879	5.258791
19	233.088	135	3.806662	5.451416
20	199.790	195	4.174387	5.297267
21	171.249	120	3.688879	5.143119
22	161.925	96	3.465736	5.087133
23	440.046	186	4.127134	6.086879
24	205.498	189	4.143135	5.325436
25	220.023	174	4.060443	5.393732
26	123.527	156	3.951244	4.81646
27	271.527	126	3.73767	5.604062
28	194.114	126	3.73767	5.268446
29	169.850	144	3.871201	5.134916
30	150.977	108	3.583519	5.017128
31	227.557	198	4.189655	5.427401
32	397.262	225	4.317488	5.984596

Table 2: Summary of Regression Analysis of Raw Data

R	R^2	Adj R^2	Std Error	F Change	Sig. F Change
0.7509	0.5639	0.5493	10.367	38.7955	< 0.0001

3.2. BTC Model for the Data

The linear model was transformed to the log-log model in form of the BTC model. The equation of the model was written in the logarithmic form as in equation (*i*) and (*iii*). The summary of the log-log regression is presented in Table 3.

Table 3: Summary of log-log regression for Highway data

Ln K	K	B	R	R^2	Adj R^2	F_{Stat}	Sig.F	RMSE
1.0300	2.8011	0.5352	0.7368	0.5428	0.5276	35.6171	<0.0001	0.2170

From the output of the analysis, the Time-Cost model for the data is

$$T = 2.80C^{0.5352} \tag{4}$$

The result indicates that the model has coefficient of determination R^2 of 0.5428 which means that only 54.28% of the variability in the data is accounted for by the model. The K value of 2.8 indicates that for a project of average cost of ₦1 million, the completion time is 2.8 days which is compared with other values of 63 and 65 for private and public buildings by Ogunsemi and Jagboro (2006) and 20.91 by Waziri (2012) for institutional building projects respectively.

The β value which demonstrates the influence of project size (measured by cost) on time performance was determined to be 0.5428. This is slightly lower than that which was obtained for residential and institutional building projects by Ogunsemmi and Jagboro (2006) and Waziri (2012) respectively. The larger value of β demonstrates somewhat a greater influence of project complexity on time prolongation. This suggests that for highway projects in Nigeria, an increase in the construction cost results in a corresponding increase in the construction time. The linear plot of the Ln Time against Ln cost is presented by Figure 2

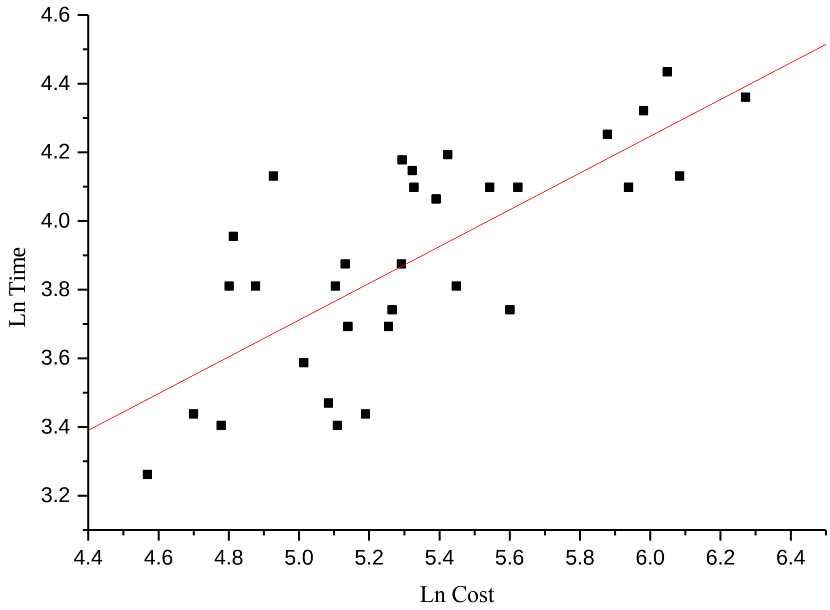

Fig. 2 Linear Plot of log-log Regression

3.3 Model Evaluation

The efficacy of the log-log model was further investigated by cross validation over a test sample of seven completed project data. The model was used to predict the completion time of the sample projects and compared with their actual durations for completion. Mean Square Error and the Mean Absolute Percent Errors of the predictions were established. The result is presented in Table 4.

Table 4: Actual and Predicted results

S/No	Construction Cost (₦'Million)	Actual Duration (Days)	Predicted Duration (Days)	Prediction Error (%)
1.	123.525	156	110.49	41.174
2.	271.760	126	168.48	-25.217
3.	194.114	126	140.73	-10.467
4.	169.850	144	141.04	9.900
5.	150.977	114	123.03	-7.336
6.	227.557	204	153.21	33.139
7.	379.262	225	201.39	11.730

The evaluation revealed that the model has maximum and minimum prediction errors of 41.17% and -25.21% respectively and average prediction error of 7.5% (Table 5). This shows that the model is not skewed toward under or over prediction. The model has a weak prediction efficacy with MAPE of 19.85 % which can be considered high for predictive models as such models are required to have absolute errors of ±10%.

Table 5: Summary of model predictive errors

Max. Error	**41.174**
Min Error	**-25.21**
Ave. Error	**7.560**
MSE	**118.71**
MAPE	**19.85**

4. Conclusion

Time and cost have long been acknowledged as important criteria for measuring the success of construction projects around the world. The trade-off between them often presents a serious challenge to project managers and sponsors of projects to come up with optimum solution for successful delivery of construction projects to the desired quality, to schedule and planned budget. The study examined the application of the BTC model to highway projects data in Nigeria. The result of the statistical analysis on the data revealed a positive relationship between the two variables of cost and time but indicating a weak fit to the log-log model which conforms to the earlier observations for building construction. The study further revealed that construction size measured by the cost has a far reaching effect on the time of completion indicated by the β value. The model also showed a weak prediction efficacy over a test sample thus making it unsuitable for high accuracy predictions. The BTC model may be employed effectively at the planning phase for feasibility and budgeting decisions. The prediction efficacy of the model could be improved by incorporating other significant variables influencing construction durations such as road length, road thickness, number of bridges, number of culverts and location adjustment factors.

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