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Stochastic Risk Analysis Framework for Building Construction Projects

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***Abstract*—**The study was carried out to establish the probability density function of some selected building construction projects of similar complexity delivered using Bill of Quantities (BQ) and Lump Sum (LS) forms of contract, and to draw a reliability scenario for each form of contract. 30 of such delivered projects are analyzed for each of the contract forms using Weibull Analysis, and their Weibull functions (α, and β) are determined based on their completion times. For the BQ form of contract delivered projects, α is calculated as 1.6737E20 and β as + 0.0115 and for the LS form, α is found to be 5.6556E03 and β is determined as + 0.4535. Using these values, respective probability density functions are calculated and plotted, as handy tool for risk analysis of future projects of similar characteristics. By input of variables from other projects, decision making processes can be made for a whole project or its components using EVM Analysis in project evaluation and review techniques. This framework, as a quantitative approach, depends on the assumption of normality in projects completion time, it can help greatly in determining the completion time probability for veritable projects using any of the contract forms under consideration. Projects aspects that are not amenable to measurement, on the other hand, can be analyzed using fuzzy sets and fuzzy logic. This scenario can be drawn for different types of building construction projects, and using different suitable forms of contract in projects delivery.

***Keywords*—**Building construction, Projects, Forms of contract, Probability density function, Reliability scenario.

I. Introduction

CONSTRUCTION is so pervasive as it involves in all facets of developmental plans by both the public and private sector of our economy. It is an essential regulator of the economy, with a kaleidoscope of so many diverse interests that could impair smooth projects execution, entraining risk to project objectives. In many developing countries, construction component takes up from 60% to 65% of their total annual budgeted expenditures; some governments go at length in reinforcing this with legislative provisions [1]. Construction project execution involves many diverse interests and is inherently loaded with occurring events that could result in some uncertainties. Part of these events and uncertainties may result from the system and can be controlled especially if they emanate from the project members. Some events such as force Majeure in the course of the project delivery cannot be controlled, and are therefore mostly unavoidable risk elements that could impair the overall project objectives. According to [2], such risks expose the client and the contractor to unfavorable situations which could affect project objectives adversely and may impair good inter personal relationship. Reference [3] sees the consequences of such decisions as uncertainties that are detrimental to project objectives as events, that have measurable probabilities and that decision and policy makers should be able to establish the probability. In Nigeria the practice of project risk assessment has been relegated mainly because the public sector is the sole client of construction. Wherein emphasis is not usually made for such practice from projects conception, through the implementation stages, therefore, both risk and environmental issues always suffer in projects delivery. However, projects financing has taken a complete departure from the traditional public sector exclusive participation, with increasing cost of capital. With prevailing economic difficulties precipitated by decline in oil revenue resulting mainly from plunging global oil price regimes, other sources of project financing became necessary. Projects in some strategic sectors of the economy are been executed through offshore loans, and joint initiative between some private sector and the government. Today projects such as the railway line construction from Lagos to Port Harcourt is been executed by some Chinese consortium on these arrangements, and the National Power Integration Projects are also based on PPPI arrangements. Therefore Public Private Partnership Initiative is gradually been embraced as an alternative by Nigerian government for infrastructure development, as posited by [4]. Such projects are usually accompanied with risk issues considerations right from the conception, and throughout the implementation stages. This is the practice that should be imbibed by the Nigerian public policy makers and construction managers, which would facilitate immensely in the planning, implementation, and reviews of projects economical execution. Wastage and sources of fund leakages in project delivery can be minimized and plugged by risk issues considerations as policy, from project conception. This should be a top priority in construction projects because of high cost of capital for project financing and obvious integration of construction industry and the economy. Reference [5] gives the contribution of the construction industry to Nigerian economy as 3 to 6% as a developing nation, and [6] gives a contribution of 40 to 60% to gross fixed capital formation (GFCF). The Nigerian construction industry has very significant relationship with the economy with backward and forward integration roles with all formal sectors of its economy [7], [6]. Reference [8] also posited that the activity based construction sector to National gross domestic product (GDP) ranges from 10 to 20%. For the sector's contribution to Nigerian GDP, [9] gave 14%, while

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[10] reported a range of 11 to 15%. This is indicating a considerable role of the construction sector to Nigerian economy, and buttressing the essentiality of considering risk issues in construction projects contracts for economical project execution.

Risk has many interpretations and facets in construction activities, [11] identified 4 major sources of risks in construction projects:

- Cost of construction;
- Completion time;
- Liabilities for latent defects;
- Quality of workmanship, and materials.

These sources are directly intertwined, and non-mutually exclusive. In this study, risk issues are considered in context of project completion, which inadvertently is linked with risk issues to cost of project on completion time and subsequent cost escalation. The magnitude of impact of risk is measured by its level of deviation from expected value according to [8] considering the effects of inherent factors in consideration. In construction industry, costs and completion time are used to determine the effects of risk allocation by the variously differing types of contract forms in terms of both budgetary and schedule escalations of the projects. References [12], [13] added that project objectives such as quality, aesthetics are also yardsticks subjectively used in measuring construction risk impact but are not directly measurable, so assumptions, checklists, experiences, etc., are deplored and subjectively analyzed in a veritable linguistic fuzzy set algorithms. Here the projects incidental data of completion time are used to determine the Weibull constants α and β using the Weibull distribution analysis. The probability density function for both the BOQ and LS contract forms delivered projects are plotted, with multiples of completion time on the x-axis, and projects unreliability on the x-axis. Thus, as a framework, the pdf can be used to determine with statistical variables, as sub processes to assess combination of risks for project of same characteristics [11]. The reliability analysis can be carried out distinctly for different types of buildings, such as residential buildings, hospital, school buildings, industrial buildings, highways, canals etc. The probability function plotted can be used as a tool for completion risk analysis in projects of similar characteristics of contract depending on which contract form is used in delivering the projects. The forms of contract are used as essential vehicles for allocating and limiting risks in construction contracts between contractor and his client, such risks are seen as the probability of some adverse effects on projects emanating as the result of some decisions in the course of the projects delivery. [12]. And, [13] posited that a decision maker should assess the probability of all the coalescing effect on projects life under the prevailing conditions.

II. Theoretical Background

For a two parameter Weibull distribution of a veritable of the data set, the cumulative density function (cdf) or unreliability is given as:

$$\mathrm{F(T)} = 1 - \overline{e}^{\left(\frac{T}{\alpha}\right)^{\beta}} \tag{1}$$

F(T) = unreliability of project failure at completion time. T = Completion time of project. α = Scale of project failure. β = Rate of project failure. e = 2.303. To determine the numerical values of these parameters, β and α – probability regression either in terms X or Y are applied, akin to maximum likelihood that is by fitting (1) into linear form.

III. Rank Regression on Y, to Determine the Weibull Parameters

Fitting (1),

$$\mathrm{F(T)} = 1 - \overline{e}^{\left(\frac{T}{\alpha}\right)^{\beta}} \quad = \text{cdf of project failure.}$$

So,

$$\ln[1 - F(T)] = -\left(\frac{T}{\alpha}\right)^{\beta} \tag{2}$$

$$= \ln[-Ln[1 - F(T)]] = \beta Ln\left(\frac{T}{\alpha}\right) \tag{3}$$

$$= Ln[[1 - F(T)]] = -\beta Ln(\alpha) + \beta Ln(T) \tag{4}$$

$$Y = Ln[-Ln[1 - F(T)]]$$

So, a= - β L_n(α) and b = β.

$$\hat{a} = y - \hat{b}\hat{x} = \sum_{i=1}^{N} yi / N - \sum_{i=1}^{N} \overline{xi} / N \tag{5}$$

$$\hat{b} = \frac{\sum_{i=1}^{N} xiyi - \sum_{i=1}^{N} xi \sum_{i=1}^{N} yi / N}{\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} xi\right) / N} \tag{6}$$

Such that:

$$yi = Ln[-Ln[1 - F(Ti)]]$$

and, xi = Ln(Ti). F(Ti)s are estimated from the median ranks of the data-set.

Once $\hat{a}$ and $\hat{b}$ are obtained from equations above the Weibull parameters of α, and β are then determined respectively.

IV. Rank Regression on X, to Determine the Weibull Parameters

Fitting (1) $F(T) = 1 - \overline{e}^{\left(\frac{T}{\alpha}\right)^{\beta}}$ is put to fit a straight line such that:

$$F(T) = 1 - \overline{e}^{\left(\frac{T}{\alpha}\right)^{\beta}} = a + b = y \text{ i.e., } x = \hat{a} + \hat{b}\,\overline{y}$$

$$\hat{a} = \overline{x} - \hat{b}\,\overline{y} = \sum_{i=1}^{N} xi/N - \sum_{i=1}^{N} yi/N \quad (7)$$

$$\hat{b} = \frac{\sum_{i=1}^{N} xi/N - \left[\sum_{i=1}^{N} xi.\sum_{i=1}^{N} yi\right] \Big/ N}{\sum_{i=1}^{N} y_i^2 - \left(\sum_{i=1}^{N} yi\right)^2 \Big/ N} \quad (8)$$

So,

$$yi = Ln\left[-Ln\left[1 - F(Ti)\right]\right] \quad (9)$$

$$x_i = L_n(T_i)$$

$F(T_i)$ = Project failure cdf.

$$y = a + bx \quad (10)$$

Solving for the parameter

$$a = \hat{a} = -\beta L_n(\alpha) \quad b = \beta = \hat{b} \quad (11)$$

F(T) = Projects failure cdf; β = Rate of project failure; α = Scale distribution of projects failure across the data set; e = 2.303; Ti = Projects completion time, i=1, 2, 3, … N = 30; Xi = Set of points on X axis for projects, i=1, 2, 3 … N=30; Yi = Set of points on Y axis for projects, i=1, 2, 3… N=30; N = Number projects delivered using respective contract form; $\hat{a}$ = Transform coefficient for fitted data in regression; $\hat{b}$ = Transform coefficient for fitted data in regression; Ln = Natural logarithms; $\sum_{i=1}^{N=30}$ = Summation for i=1,2,3,4 … N=30.

TABLE I
ESTIMATING THE WEIBULL PARAMETERS FOR BQ CONTRACT DELIVERED PROJECTS

N(i)	Ti	(In(Ti)	F(Ti)	Yi	$(\ln(Ti)^2$	Yi^2	(In Ti)yi
1	400	5.9915	0.0230	-3.7606	35.8981	14.1421	-22.5316
2	480	6.1738	0.0559	-2.8556	38.1158	8.1545	-17.6299
3	496	6.2066	0.0888	-2.3752	38.5222	5.6416	-14.7419
4	560	6.3279	0.1217	-2.0420	40.0423	4.1698	-12.9216
5	576	6.3561	0.1546	-1.7841	40.4000	3.1830	-11.3399
6	584	6.3699	0.1875	-1.5719	40.5756	2.4709	-10.0128
7	592	6.3835	0.2204	-1.3904	40.7491	1.9332	-9.5034
8	608	6.4101	0.2533	-1.2307	41.0894	1.5146	-7.8889
9	616	6.4232	0.2862	-1.0872	41.2575	1.1820	-6.9833
10	624	6.4361	0.3191	-0.9562	41.4234	0.9143	-6.1542
11	640	6.4615	0.3520	-0.8350	41.7509	0.6972	-5.3954
12	656	6.4862	0.3849	-0.7216	42.0708	0.5207	-4.6804
13	664	6.4982	0.4178	-0.6144	42.2266	0.3774	-3.9925
14	672	6.5102	0.4507	-0.5123	42.3827	0.2625	-3.3352
15	680	6.5220	0.4836	-0.4142	42.5365	0.1716	-2.7014
16	688	6.5338	0.5164	-0.3195	42.6905	0.1021	-2.0875
17	704	6.5568	0.5493	-0.2270	42.9916	0.05153	-1.4884
18	768	6.6438	0.5822	-0.1361	44.1400	0.0185	-0.9042
19	800	6.6846	0.6151	0.0463	44.6839	0.0021	0.3095
20	848	6.7429	0.6480	0.0431	44.4667	0.0019	0.2906
21	1072	6.9773	0.6809	0.1330	48.6827	0.0177	0.9280
22	1320	7.1854	0.7138	0.2240	51.6300	0.0502	1.6095
23	1640	7.4025	0.7467	0.3171	54.7970	0.0993	2.3473
24	1696	7.4360	0.7796	0.4136	55.2941	0.1711	3.0755
25	1696	7.4360	0.8125	0.5152	55.2941	0.2654	3.8310
26	1872	7.5348	0.8454	0.6243	56.7732	0.3898	4.7040
27	1984	7.5929	0.8783	0.7449	57.6521	0.5549	5.6560
28	2120	7.6592	0.9111	0.8839	58.6633	0.7813	6.7600
29	2160	7.6779	0.9440	1.0586	58.9501	0.8911	8.1278
30	2232	7.7107	0.9777	1.3358	59.4549	1.7844	10.3000
Σ	=	203.3314		-16.4942	1385.2051	50.5167	-96.3533

yi = In {-In[1-F(Ti)]}
(i = 1,2, -3, … N, N=30)

V. Estimating the Weibull Parameters, Alpha and Beta (α, β)

The Weibull parameters are calculated for the projects delivered using the BQ form of contract.

Utilizing the values in Table I, β and $\hat{a}$ (α) can be determined as:

$$\hat{b} = \frac{\sum_{i=1}^{30}(InTi)\ yi - \sum_{i=1}^{30}(InTi)\ (\sum_{i=1}^{30} yi)/N}{\sum_{i=1}^{30}(InTi)^2 - \sum_{i=1}^{30}(InTi)^2\ /N}$$

= [-96.3533-203.3314* (-16.4942)/30]/1385.2051-1385.2051/30.

Therefore, $\hat{b}$ = 15.4383/1339.0313. = + 0.0115.

$$\hat{a} = \overline{Y} - \hat{b}\,\mathrm{T} = \sum_{i=1}^{30} yi/N - \hat{b}\sum_{i=1}^{30} InTi/N$$

$$= \sum_{i=1}^{30} yi/N - \hat{b}\sum_{i=1}^{30} InTi$$

Substituting the numerical values from Table I:

$\hat{a}$ = [(-16.4942/30 – .0115* (203.3314/30)] = -0.6277

$\hat{a}$ = - 0.6277, and $\hat{b}$ = + 0.0115.

$$\alpha = \frac{\hat{a}}{\hat{\beta}} = e\,^\wedge\ \text{-0.6277/+ 0.0115} = \mathit{1.6737\ E20.}$$

TABLE II
ESTIMATING THE WEIBULL PARAMETERS FOR LS CONTRACT DELIVERED PROJECTS

N(i)	Ti	(In(Ti)	F(Ti)	Yi	$(\ln(Ti)^2$	Yi^2	(In Ti)yi
1	896	6.7979	0.0230	-3.7606	46.2174	14.1421	-25.5454
2	904	6.8068	0.0559	-2.8556	46.3325	8.1545	-19.4375
3	1008	6.9157	0.0888	-2.3752	47.8269	5.6416	-16.4262
4	1152	7.0493	0.1217	-2.0420	49.6926	4.1698	-14.3847
5	1168	7.0630	0.1546	-1.7841	49.8860	3.1830	-12.6011
6	1280	7.1546	0.1875	-1.5719	51.1883	2.4709	-11.2463
7	1288	7.1608	0.2204	-1.3904	51.2771	1.9332	-9.9564
8	1312	7.1793	0.2533	-1.2307	51.5423	1.5146	-8.8356
9	1392	7.2385	0.2862	-1.0872	52.3959	1.1820	-7.8670
10	1424	7.2612	0.3191	-0.9562	52.7250	0.9143	-6.9432
11	1472	7.2944	0.3520	-0.8350	53.2083	0.6972	-6.0908
12	1520	7.3265	0.3549	-0.7216	53.6776	0.5207	-5.2868
13	1600	7.3778	0.4178	-0.6144	54.4319	0.3774	-4.5329
14	1664	7.4170	0.4507	-0.5123	55.0119	0.2625	-3.7997
15	1728	7.4547	0.4836	-0.4142	55.5726	0.1716	-3.0877
16	1760	7.4731	0.5164	-0.3195	55.8472	0.1021	-2.3866
17	1808	7.4999	0.5493	-0.2270	56.2485	0.05153	-1.6702
18	1824	7.5088	0.5822	-0.1361	56.3821	0.0185	-1.0219
19	1872	7.5348	0.6151	-0.0463	56.7732	0.0021	-0.3489
20	1888	7.5433	0.6480	0.0431	56.9014	0.0019	0.3251
21	1904	7.5517	0.6809	0.1330	57.0282	0.0177	1.0044
22	1928	7.5642	0.7138	0.2240	57.2171	0.0502	1.6921
23	1940	7.5704	0.7467	0.3171	57.3110	0.0993	2.4006
24	1992	7.5969	0.7796	0.4136	57.7129	0.1711	3.1421
25	2064	7.6324	0.8125	0.5152	58.2535	0.2654	3.9322
26	2072	7.6363	0.8454	0.6243	583131	0.3898	4.7673
27	2160	7.6779	0.8783	0.7449	58.9501	0.5549	5.7193
28	2400	7.7832	0.9111	0.8839	60.5782	0.7813	6.8796
29	2736	7.9143	0.9440	1.0586	62.6361	0.8911	8.3781
30	4928	8.5027	0.9777	1.3358	72.2959	1.7844	11.3579
Σ	=	222.4771		-16.4942	1653.9238	50.5167	111.8802

yi = In {-In[1-F(Ti)]}
(i = 1,2, -3, … N, N=30)

TABLE III
CALCULATED VALUES OF WEIBULL PARAMETERS, (A, AND B) FOR BQ AND LS DELIVERED PROJECTS

Contractual option	Calculated Weibull parameters	
	α	β
BQ contract delivered projects	1.6737E20	+ 0.0115
LS contract delivered projects	5.6556E03	+ 0.4535

The Weibull parameters in respect of projects delivered using the Lump Sum form of contract are calculated using the values obtained in Table II:

$$\hat{b} = \frac{\sum_{i=1}^{30}(InTi)\ yi - \sum_{i=1}^{30}(InTi)\ (\sum_{i=1}^{30} yi)/N}{\sum_{i=1}^{30}(InTi)^2 - \sum_{i=1}^{30}(InTi)^2\ /N}$$

$\hat{b}$ = [111.8802 – (-16.4942) /30 *111.8802] / [1653.9238 – (1653.9238) 30] = +0.4535

$$\hat{a} = \overline{Y} - \hat{b}\,\mathrm{T} = \sum_{i=1}^{30} yi/N - \hat{b}\sum_{i=1}^{30} InTi\ \ /N$$

$$= \sum_{i=1}^{30} yi \;/\; N \;\; - \hat{b} \sum_{i=1}^{30} InTi \qquad\qquad \alpha \;=\; \frac{\hat{a}}{\hat{\beta}} = e^{\wedge} \;+2.8133 \,/\, +0.4535 = 5.6556E03.$$

$\hat{a}$ = [(-16.4942) / 30 – (+ 0.4535* (222.4771)/30] = + 2.8133

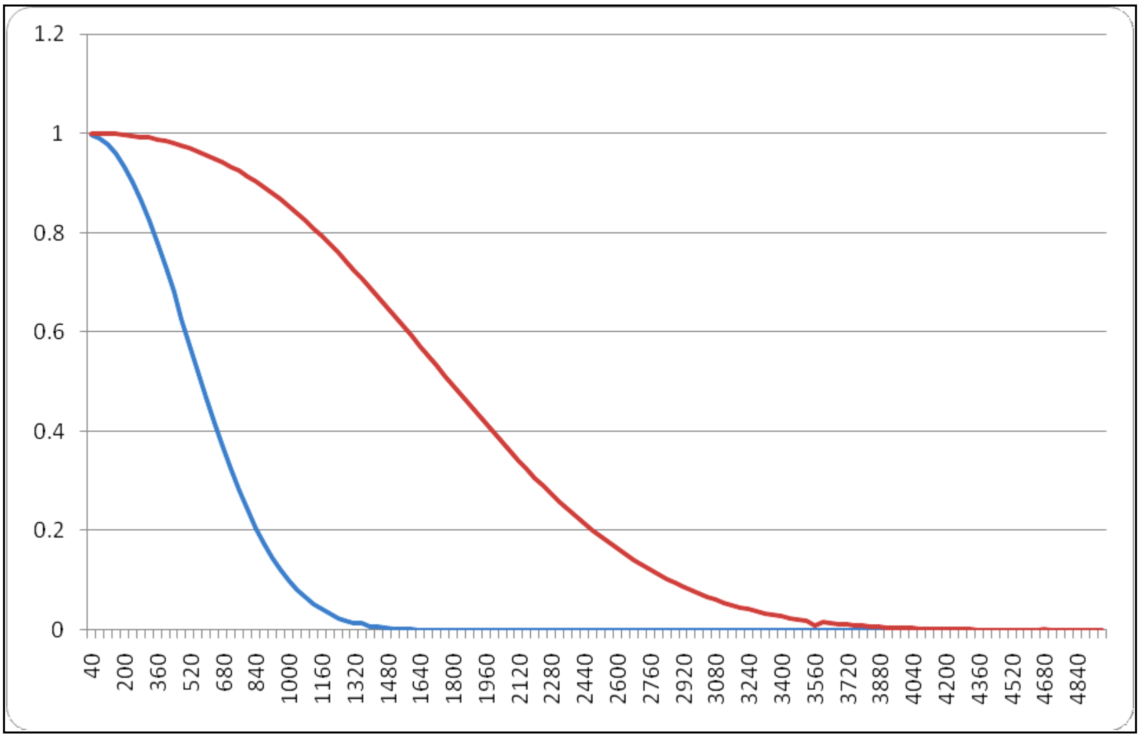

Fig. 1 pdf for BQ and LS contracts delivered projects

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