Schedule Performance of Residential Project by Using Weibull Analysis

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***Abstract**-In every project, construction managers regularly monitor projects to ensure that the project performance is under control. Traditionally, the earned value method (EVM) is widely used tool to control and monitor schedule performance using the schedule and cost performance indices which compare the budgeted cost of work performed to what was originally scheduled or what is actually expended. However, its application to schedule performance forecasting has been limited due to poor accuracy in predicting project durations. Recently, several EVM-based schedule forecasting methods were introduced. This paper presents a statistical approach, namely Weibull analysis, to evaluate stochastically the schedule performance of construction. This can be used in conjunction with the EVM to enhance the evaluation and control of schedule performance. The objective of this study is to discuss and present the applicability of Weibull analysis to evaluate stochastically the schedule performance of construction project. This study focuses on schedule performance with probabilistic method. Currently available methods, for example, the critical path method (CPM) and earned value management (EVM) are deterministic and fail to account for the inherent uncertainty in forecasting and project schedule performance. In this paper, the applicability of Weibull analysis for evaluating and comparing the performance of the building project is presented. The various steps in the analysis are discussed along with an example.*

Keywords-Construction; Cost control; EVM; Schedule performance; Weibull analysis.

I. INTRODUCTION

The construction industry is vital for the development of any nation. In many ways, the pace of the economic growth of any nation can be measured by the development of physical infrastructures, such as buildings, roads and bridges. Construction project development involves numerous parties, various processes, different phases and stages of work and a great deal of input from both the public and private sectors, with the major aim being to bring the project to a successful conclusion. The objective of construction planning and controls, a basic project management function, is to ensure a well coordinated and successful project. A basic element of planning is the setup of objectives. The objectives will guide the many decisions made during the project's life. These decisions involve tradeoffs between schedule, cost, quality, and other performance attributes. Effective monitoring of the progress of construction projects requires the integration and quantification of the various aspects of performance. The traditional performance indicators in the construction industry are completion time, cost, and quality. Most current project control systems measure quantitatively cost and schedule status and forget other major aspects of project performance like cash flow, profitability, quality, safety, project team satisfaction, and client satisfaction which are in some cases as important as cost and schedule. Very few project management systems quantify the later project attributes and they do so independently without proper integration to the overall project performance.

Project control process consists of monitoring actual performance, comparing it with planned performance, analyzing the difference, and forecasting the final outcomes at completion resulting from management actions. The schedule performance of construction projects often deviates from the baseline plan. Lack of precise knowledge about the sources of these deviations makes it hard for project management teams to control the project schedule performance and ensure the timely project delivery.

II. RESEARCH OBJECTIVE

The objective of this study is to discuss and present the applicability of Weibull analysis to evaluate stochastically the schedule performance of construction. In this paper, an example is provided, in which the performance of two buildings are compared and analyzed. In general, the ultimate goal of this research study is to check the feasibility of Weibull distribution for the project performance in consideration of Earned value technique.

In the next section of this paper, briefly covers the EVM and performance indices. The second part is to discussion about Weibull distribution characteristics and its applications to EVM. Then this section is followed by an example of Weibull analysis using actual site data of Schedule performance index. And at last conclusions are drawn.

III. METHODOLOGY

Earned value Method and Performance Indices

Earned Value management (EVM) is widely used method of performance measurement. Earned Value is a project management technique that uses "work in progress" to indicate what will happen to work in the future. Earned Value is an enhancement over traditional accounting progress measures. Traditional methods focus on planned, accomplishment (expenditure) and actual costs. The earned value technique is superior to independent schedule and cost control for evaluating work progress in order to identify potential schedule slippage and areas of budget overruns. The general expressions for the cost and schedule performance indices are:

Schedule performance index (SPI) = BCWP/BCWS

Cost performance index (CPI) = BCWP/ACWP

For a more detailed explanation of the earned value method (see Fleming and Koppelman (2002); Kim and Ballard (2002)).

Weibull Distribution

Weibull distribution is named after Walodi Weibull (1887 – 1979). It is very flexible and can through an appropriate choice of parameters and model many types of failure rate behaviors. This distribution can be found with two or three parameters; scale, shape and location parameters. There are a number of methods for estimating the values of these parameters; some are graphical and others are analytical. Graphical methods include Weibull probability plotting and hazard plot. These methods are not very accurate but they are relatively fast. The analytical methods include maximum likelihood method, least square method and method of moments. These methods are considered as more accurate and reliable compared to the graphical method.

The Weibull analysis is that technique in which statistical data is analyze. This type of analysis permits to determine the failure behavior of the mechanical seal, bearings, shaft and impeller. The Weibull distribution is frequently used for its great variety of shapes that able to many types of data, especially data relating to component life. Weibull analysis includes following features:

1. Forecasting and prediction of failure data.
2. Maintenance planning and cost effective replacement strategies.
3. Calibration of complex design system i.e. CAD/CAM, finite analysis etc.
4. Evaluating corrective action plan.
5. Spare parts forecasting.

The Weibull distribution or probability density function has two parameters:

1. Shape Parameter (β) – it defines the shape of the distribution.
2. Scale Parameter (α) – it defines the spread of the distribution.

A distribution is mathematically defined by its probability distribution function equation (pdf). The most general expression of the Weibull pdf is given by the three parameter Weibull distribution expression as,

$$f(x) = \frac{\beta}{\alpha}\{\frac{x-\gamma}{\alpha}\}^{\beta-1} e^{-(\frac{x-\gamma}{\alpha})^{\beta}}$$

Where, $f(x) \geq 0, x \geq 0$

$\alpha \geq 0 \beta \geq 0$

$-\infty < \gamma < +\infty$

And, α= Scale Parameter

β= Shape Parameter or Weibull slope

γ= Location parameter

Weibull distributions come in two and three-parameter variants. A third parameter can be successfully used to describe failure behaviour when there is a time period where no failure can occur (e.g. ball bearing failures due to wear). But in most other cases, a two parameter description is preferable. Frequently, the location parameter is not used, and the value for this parameter can be set to zero. When this is the case, the pdfequation reduces to that of two parameter Weibull distribution. There is also a form of the Weibull distribution known as the one parameter Weibull distribution. The two parameter Weibull pdf when γ=0 as,

$$f(x) = \frac{\beta}{\alpha}(\frac{x}{\alpha})^{\beta-1} e^{-(\frac{x}{\alpha})^{\beta}} \text{......................} (1)$$

As was mentioned previously, the Weibull distribution is widely used in reliability and life data analysis due to its versatility. Depending on the values of the parameters, the Weibull distribution can be used to model a variety of life behaviours. An important aspect of the Weibull distribution is how the values of the shape parameter β, and the scale parameter α, affect such distribution characteristics as the shape of the pdf curve, the reliability and the failure rate.

The Weibull shape parameter, β, is also known as the Weibull slope. This is because the value of β is equal to the slope of the line in a probability plot. Different values of the shape parameter can have marked effects on the behaviour of the distribution. In fact, some values of the shape parameter will cause the distribution equations to reduce to those of other distributions. The Weibull shape parameter, β, indicates whether the rate of the considered performance characteristic is increasing, constant or decreasing. The parameter β is a pure number (i.e., it is dimensionless). For example: When $\beta<1.0$ indicates that the characteristic has a decreasing rate and a $\beta>1.0$ indicates an increasing rate. The following fig. 1 shows the effect of different values of the shape parameter, β, on the shape of the pdf (while keeping γ constant). One can see that the shape of the pdf can take on a variety of forms based on the value of β.

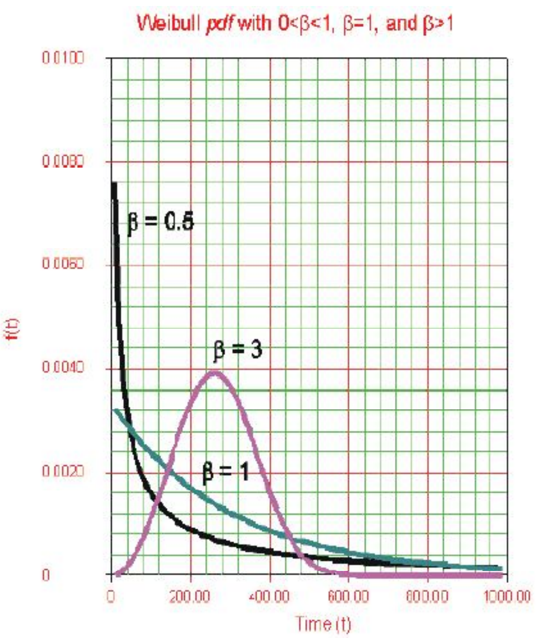

Fig.1. Weibull distribution with different scale parameter

IV. ANALYSIS

In this section, the analysis is carried out which is explained step by step featuring two buildings can be analysed and compared.

Step 1:

In this step, the planned hours, actual complete and percent complete of two buildings data is collected. Then schedule performance index is calculated of both buildings which is shown in Table 1. A spreadsheet formulation was developed for the calculation of analysis.

Step 2:

In this step, the calculated SPI data for both the project is fitted to the the Weibull cumulative distribution function (CDF). The Weibull CDF is given by,

$$f(x) = 1 - e^{-(\frac{x}{\alpha})^{\beta}} \text{ .... } (2)$$

The type of Weibull distribution discussed above in Eqs. (1) & (2) is called two parameter Weibull distributions. The median rank method is used for the ranking of SPI values and then using an appropriate transformation, the two-parameter Weibull model (α, β) can be represented by a straight line and therefore the two parameters (α, β) can be determined using simple linear regression (Henley and Kumamoto 1996). The median rank method is demonstrated in Table 3a. The median rank of each data point is calculated next as (rank no.−0.3)/ (no. of points+0.4). For example, for Project A the fourth point median rank is equal to (4−0.3)/ (19+0.4) = 0.1907. It can be shown mathematically (Ireson and Coombs (1988)), that value of ln(ln(1/1-median rank) plots as a straight line against ln(SPI) for the SPI data points as shown in fig. 2. the straight line is in the form of y=mx+b, it can also be shown that the β parameter=m, and the α parameter= e(b/β). The trend line drawn through each set of points indicates that the SPI datasets for D-building appropriately fit the Weibull distribution. Now it is possible to use regression analysis to evaluate scale and shape (α and β) parameters. The Analysis Tool-Pak add-in that is built into MS EXCEL was used for the regression analysis. Table 2 lists the parameters for each project calculated by regression analysis.

Step 3:

In this step, the probability of attaining the certain index values is determined i.e. certain index values. The performance probability determined using the EXCEL's built-in Weibull function as: =WEIBULL (index value, shape parameter, scale parameter, TRUE). The performance probability and reliability of D-building is shown in table 4.

Table 1: Data set from D-Building

Sr. no.	Month	Planned hours	Percent Cumulative Planned hours	Percent Planned this period	Actual hours	Percent Cumulative Actual hours	Percent Spent this period	Percent complete	Percent complete this period	SPI
1	Jun-15	16	0.01	0.01	16	0.01	0.01	0.05	0.05	5.00
2	Jul-15	3600	2.15	2.1	3600	2.2	2.1	1	0.95	0.44
3	Aug-15	4400	2.63	0.5	4400	2.6	0.5	2	1	2.09
4	Sep-15	5456	3.26	0.6	5456	3.3	0.6	2.3	0.3	0.48
5	Oct-15	7792	4.66	1.4	8048	4.8	1.5	2.9	0.6	0.43
6	Nov-15	11304	6.75	2.1	11680	7.0	2.2	3	0.1	0.05
7	Dec-15	28992	17.32	10.6	29352	17.5	10.6	6	3	0.28
8	Jan-16	31216	18.65	1.3	31408	18.8	1.2	7	1	0.75
9	Feb-16	50368	30.09	11.4	50624	30.2	11.5	9	2	0.17
10	Mar-16	72328	43.21	13.1	72576	43.4	13.1	12	3	0.23
11	Apr-16	87872	52.50	9.3	88136	52.7	9.3	14	2	0.22
12	May-16	88336	52.78	0.277	88600	52.9	0.3	16	2	7.21
13	Jun-16	103312	61.73	8.9	103816	62.0	9.1	19	3	0.34
14	Jul-16	119544	71.43	9.7	120160	71.8	9.8	20	1	0.10
15	Aug-16	131776	78.73	7.3	132400	79.1	7.3	22	2	0.27
16	Sep-16	143448	85.71	7.0	143952	86.0	6.9	23	1	0.14
17	Oct-16	156088	93.26	7.6	156576	93.6	7.5	25	2	0.26
18	Nov-16	167368	100.00	6.7	167904	100.3	6.8	27	2	0.30

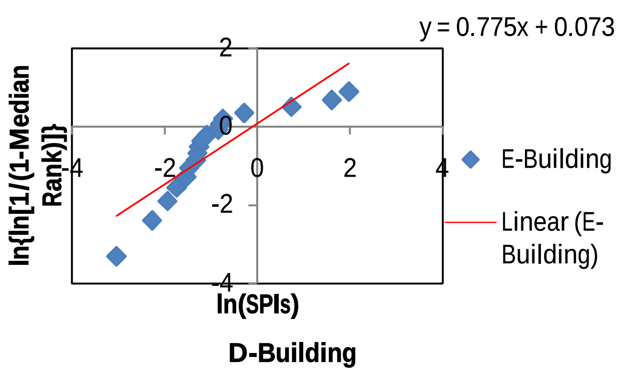

Fig. 2 Goodness of fit test on D-Building data

Step 4:

In this final step, the two buildings (D & E) are compared in terms of reliability using a performance graph. The results are shown in fig. 4 which shows equal chances of meeting schedule performances. The D-building has a higher chance of meeting a schedule. The schedule performance is used updated regularly to compare the projects or according to Chang (2001) index values equal to or above 0.9 indicate average to above-average performance (from average to excellent) as well as index values less than 0.9 indicate performance less than average (from average to unsatisfactory). The performance graph can be used for the making decisions on the resource assignment and accelerating the project.

Table 2: Parameter Settings as a Result of Regression Analysis

Total: 18	Coefficients
Intercept	0.07287836
ln(SPIs)	0.77441952
Beta or Shape parameter	0.77441952
Alpha or Slope parameter	1.09867739

Table 3a: Median Ranks Method of fitting a Data Set of D-Building

SPI values	Rank	Median Rank	1/(1-Median Rank)	ln{ln[1/(1-Median Rank)]}	ln(SPI values)
0.05	1	0.03608247	1.037433155	-3.30362951	-3.04374597
0.10	2	0.08762887	1.096045198	-2.389141012	-2.27195981
0.14	3	0.13917526	1.161676647	-1.89802475	-1.94216802
0.17	4	0.19072165	1.23566879	-1.552999198	-1.74423517
0.22	5	0.24226804	1.319727891	-1.28220259	-1.53550274
0.23	6	0.29381443	1.416058394	-1.05590564	-1.47558553
0.26	7	0.34536082	1.527559055	-0.858797897	-1.32869441
0.27	8	0.39690722	1.658119658	-0.681842867	-1.29588349
0.28	9	0.44845361	1.813084112	-0.51914459	-1.25924936
0.30	10	0.50000000	2	-0.366512921	-1.21485927
0.34	11	0.55154639	2.229885057	-0.220708967	-1.09281184
0.43	12	0.60309278	2.519480519	-0.078986134	-0.84424089
0.44	13	0.65463918	2.895522388	0.061250816	-0.81274799
0.48	14	0.70618557	3.403508772	0.202783192	-0.74343619
0.75	15	0.75773196	4.127659574	0.349043287	-0.28428258
2.09	16	0.80927835	5.243243243	0.504972676	0.73816835
5.00	17	0.86082474	7.185185185	0.679059054	1.60943791
7.21	18	0.91237113	11.41176471	0.889800879	1.97604270

Table 3b Data Set from E-Building

Month	Planned hours	Percent Cumulative Planned hours	Percent Planned this period	Actual hours	Percent Cumulative Actual hours	Percent Spent this period	Percent complete	Percent complete this period	SPI
Jun-15	3840	2.1	3.5	3840	2.1	3.5	1	1	0.29
Jul-15	4176	2.3	0.2	4184	2.3	0.2	2	1	5.38
Aug-15	4608	2.5	0.2	4560	2.5	0.2	2.96	0.96	4.02
Sep-15	5784	3.2	0.7	6336	3.5	1.0	3	0.04	0.06
Oct-15	16384	9.1	5.9	16624	9.2	5.7	4	1	0.17
Nov-15	27352	15.1	6.1	27744	15.3	6.1	6	2	0.33
Dec-15	32208	17.8	2.7	32656	18.1	2.7	6.2	0.2	0.07
Jan-16	45272	25.0	7.2	45472	25.1	7.1	8	1.8	0.25
Feb-16	71088	39.3	14.3	71336	39.4	14.3	11	3	0.21
Mar-16	76944	42.5	3.2	77192	42.7	3.2	13	2	0.62
Apr-16	83704	46.3	3.7	84168	46.5	3.9	16	3	0.80
May-16	107656	59.5	13.2	108104	59.8	13.2	19	3	0.23
Jun-16	122000	67.4	7.9	122600	67.8	8.0	21	2	0.25
Jul-16	132368	73.2	5.7	133056	73.6	5.8	22	1	0.17
Aug-16	146296	80.9	7.7	146952	81.2	7.7	24	2	0.26
Sep-16	157272	86.9	6.1	158480	87.6	6.4	25	1	0.16
Oct-16	168344	93.1	6.1	169696	93.8	6.2	30	5	0.82
Nov-16	180896	100.0	6.9	181968	100.6	6.8	31	1	0.14

The same procedure is carried out for the calculations of median rank and Goodness of fit for the evaluation of the reliability of schedule performance of E-Building. The graph of Goodness of fit is for E-Building is shown in fig. 3.

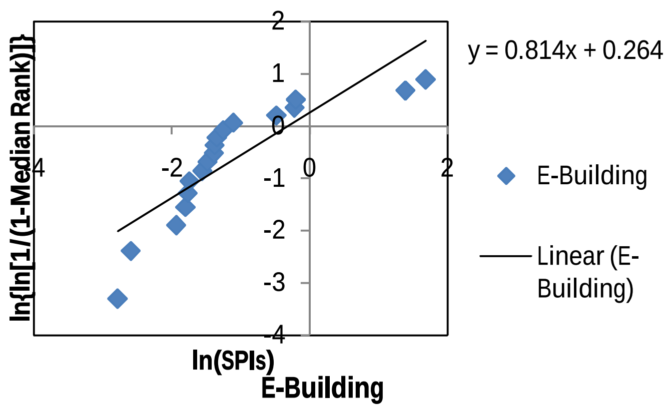

Fig. 2 Goodness of fit test on E-Building data

Table 4: Performance Probability and Reliability for D and E-Building

Index Range	D-Building		E-Building	
	Percentage Probability	Reliability	Percentage Probability	Reliability
0.1	0.100	0.900	0.054	0.946
0.2	0.202	0.798	0.134	0.866
0.3	0.297	0.703	0.222	0.778
0.4	0.384	0.616	0.312	0.688
0.5	0.461	0.539	0.399	0.601
0.6	0.530	0.470	0.481	0.519
0.7	0.591	0.409	0.556	0.444
0.8	0.645	0.355	0.623	0.377
0.9	0.692	0.308	0.683	0.317
1	0.734	0.266	0.735	0.265
1.1	0.770	0.230	0.781	0.219
1.2	0.801	0.199	0.819	0.181
1.3	0.829	0.171	0.852	0.148
1.4	0.853	0.147	0.880	0.120
1.5	0.873	0.127	0.903	0.097
1.6	0.891	0.109	0.922	0.078
1.7	0.906	0.094	0.937	0.063
1.8	0.920	0.080	0.950	0.050
1.9	0.931	0.069	0.960	0.040
2	0.941	0.059	0.969	0.031
2.1	0.950	0.050	0.975	0.025
2.2	0.957	0.043	0.981	0.019
2.3	0.963	0.037	0.985	0.015
2.4	0.969	0.031	0.988	0.012
2.5	0.973	0.027	0.991	0.009
2.6	0.977	0.023	0.993	0.007
2.7	0.980	0.020	0.995	0.005
2.8	0.983	0.017	0.996	0.004
2.9	0.986	0.014	0.997	0.003
3	0.988	0.012	0.998	0.002
3.1	0.990	0.010	0.998	0.002
3.2	0.991	0.009	0.999	0.001
3.3	0.993	0.007	0.999	0.001
3.4	0.994	0.006	0.999	0.001
3.5	0.995	0.005	0.999	0.001
3.6	0.995	0.005	1.000	0.000

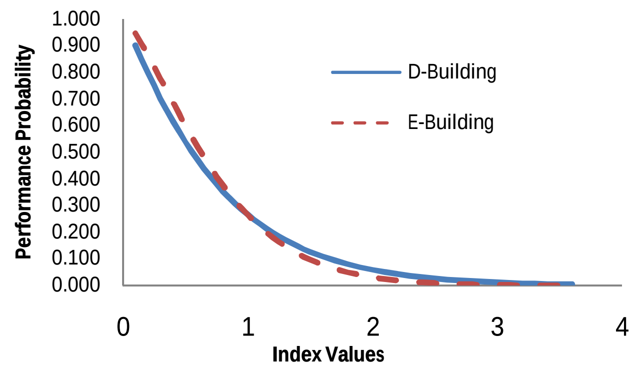

Fig. 4 Performance Graph

V. CONCLUSION

Every project must be completed in scheduled time and in budgeted cost, but meeting with customer's dynamic expectation, it becomes very difficult to manage the things for project manager. The main objective is keeping the project on schedule and within budget cost. EVM is common technique for cost and schedule control through sampling cost per schedule performance C/SPI index during project.

In this paper, Weibull distribution is thoroughly studied and checks the applicability and feasibility of same by using an example. Weibull analysis for probabilistic analysis of the C/SPI is presented. For the analysis simply four steps procedure is carried out for analyzing a set of SPI data, using the Weibull analysis method, was also presented. The strongest advantage of Weibull analysis is the ability to provide accurate performance analysis and risk predictions with extremely small samples (Abernathy and Fulton 2001). This analysis can be easily carried out on spreadsheet software. The results were presented in a performance graph, which can be used to determine the probabilities of reaching a certain index value or range of values. From the study, it is concluded that Weibull analysis is feasible for the evaluation of schedule performance of an actual project. Also it is robust and efficient technique of schedule performance which give actual results.

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