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A Review on Weibull Analysis for Performance Evaluation in Construction Project

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Abstract: In construction projects, construction project managers monitor and control the project performance to ensure the project is under control. The Earned Value Management (EVM) method is a tool that integrates three critical elements of project management: scope management, cost management, time management. EVM is traditionally used to monitor and control the project performance by using cost and schedule indices. EVM is widely used to forecast project cost and time at completion. However, the application of EVM is limited due to poor accuracy in forecasting cost and schedule performance. Conventional EVM has inability to address the uncertainties as well as their causes and effects. Recently, many EVM-based cost and schedule performance forecasting methods were introduced by many researchers. This study describes the major aspects of EVM and useful statistical techniques to enhance the effective application of EVM in project management. Further it includes the overview of a statistical approach to refine and improve the performance of conventional EVM by introduction of Weibull Analysis. This can be used in addition with EVM to give probabilistic approach to evaluate cost and schedule performance in construction project.

Keywords: construction management; cost control; cost performance; schedule performance; earned value management method; weibull analysis.

I. INTRODUCTION

The construction industry is one of the vital industries of today that has great contribution for the development of nation. It has phenomenal impact on the economy of nation. Construction sector and activities are main sources of economic growth, development and economic activities. It is an important sector that contributes mainly in improving Gross Domestic Product (GDP) of country. Construction project development involves development of physical infrastructure such as building of dam, roads, real estate, bridges, monuments and wooden structures. The Construction Industry is an investment oriented sector where government appears highly interested. Government contracts with Construction contractors to develop infrastructure related to health, education and transport sector. For prosperity of any nation, construction Industry is essential. This industry involves various parties, processes, different phases and stages of work. Both public and private sectors have great involvement in this industry. Major aim of construction project is to bring a project to successful conclusion for which proper project performance management is required. The objective of construction planning and control is to assure that project is well coordinated and completed on stipulated time. 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. The integration and quantification of the various aspects of performance are required for effective monitoring and control of construction projects. In the construction industry the traditional performance indicators 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 and safety also project team and client satisfaction. These aspects are as important as cost and schedule in some cases. Very few project management systems quantify the later project attributes and they do so independently without proper integration to the overall project performance. Project controlling process exist of monitoring actual performance, comparing it with planned performance. Further it also consist analyzing the difference, and forecasting the outcomes at completion resulting from management actions. The schedule and cost 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 [1].

A project is any endeavor involving planned action to achieve successful unique product or services. Primary factors for a project to be successful are applying performance measurement and feedback tool. In construction projects, construction managers monitor and control the project performance to complete the project successfully. Earned value

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management (EVM) is one of the leading project performance measurement tool for managing the project. Purpose of EVM is to control cost overruns and time delays in construction projects. EVM is often used as an objective technique for supporting the tasks of monitoring, analyzing, and forecasting project cost and schedule performance. Earned-value management is a method integrating a project's cost, schedule, and scope metrics into a single measurement system [2]. It shows that cost variation may affect the schedule progress and vice versa, i.e., a project that is behind the schedule or ahead of schedule can directly affect the cost plan.

In particular, EVM is a widely acknowledged method to calculate cost and schedule performance indices of an ongoing project based on current progress status and performance. Major contributions to EVM were established in the 1990s within U.S. defense projects. The construction industry as compared to other industries experienced small implementation of these findings and during the past ten years little advancement in project performance forecasting research for construction projects has been noted [3]. EVM has entitled for the measurement of computable project performance indicators and predictors of future performance. It helps construction project managers to effectively manage their projects and can take corrective actions. Later part of paper consist of detailed explanation of earned value method.

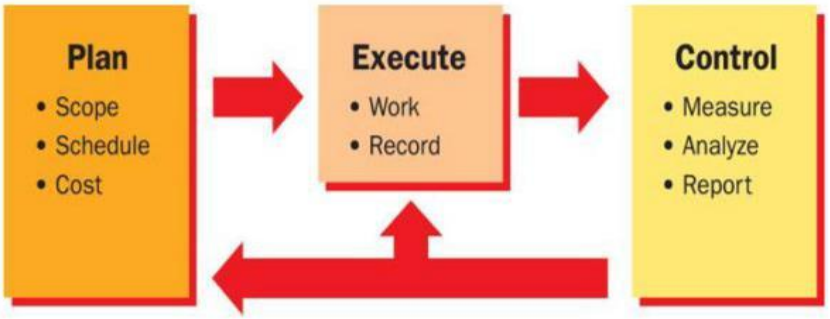

Fig. 1. EVM and basic PM process [4]

In the EVM, the cost and schedule performance indices (C/SPI) are used for consistent monitoring and controlling of the project's cost and schedule based on an original critical path method (CPM) schedule [5]. Traditional, EVM monitoring of project performances is based on the cost variance (CV) and schedule variance (SV), or cost performance index (CPI) and schedule performance index (SPI). Although the EVM approach is considered to be the most objective method available in the measurement of project performances, the method is limited and does not directly account for variation in individual performance values about a normal or natural level of project performances. A gap exists between the use of existing methods and the availability of an appropriate methodology that specifically addresses variations in performances [6].

Unfortunately, CPM scheduling creates an unrealistic expectation regarding project schedule performance. Starting a construction project one day and expecting that the project will finish on an exact date after some two or three years in the future is unrealistic. Therefore, there is a need to evaluate performance measurement techniques, like the EVM, to provide means for probabilistically analyzing the schedule performance and measuring the risks involved [7]. In past years many EVM-based cost and schedule performance techniques were introduced by many researchers. The work related to evaluation of cost and schedule performance is discussed in the next section of paper.

II. RELATED WORK

Reliable forecasting is a major element of successful project management. In the aspect of project uncertainties, applicable forecasting is required to help project managers make right decisions about the future based on the forecasts. If forecasted outcomes are not satisfactory, corrective measures are needed to compensate for the deviations [8-9]. As a result, using the appropriate probabilistic forecasting tool can lead to more accurate decisions

EVM is considered as an adaptable tool in evaluation of project cost and schedule performance. Though, the applicability of the conventional EVM to the evaluation and forecasting of cost and schedule performance has been widely criticized for many reasons [10]. First, it is reported that EVM uses units of cost rather than time to measure the schedule performance of the project [11]. However, it is a suitable expectation for the schedule indices of a project to be reported in units of time. Hence, the EVM may be unfavorable for decision makers and the project management team. Secondly, it undergoes from a systematic saturation as the project approaches its completion, generally in the final stage of the project. This distortion leads the final SPI to be indicative of a performance according to planned, regardless of the fact that the project is actually on, behind, or even ahead of the baseline plan. This a major disadvantage considering the fact that top executives are not necessarily trained to be fully aware of the characteristics of the EVM schedule indicators [10-11].

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In addition, there are another two drawbacks to the EVM when it is used as a means of forecasting either time or cost for construction project. Any practice in construction industry involves internal uncertainty and EVM have deterministic nature; therefore, it is not able to address the related uncertainties. Also it is unable to provide the project manager with bounds of possible conclusions according to the actual schedule performance [12]. The prediction errors early in the project that are primarily a result of the lack of enough available data is another shortcoming that has been addressed in the literature when the EVM is used for cost and schedule evaluation of the project [12-13].

Encountered with project uncertainties, researchers often use statistical and probabilistic approach to provide subjective estimates and fit curves to observed data. Specifically, in the program evaluation and review technique (PERT), three-point estimation is made based on beta distribution [14]. AbouRizk and Halpin (1992) [15] conducted a study about fitting probability distributions such as normal, uniform, gamma, exponential, beta, and lognormal to construction duration data and concluded that this type of data can assume a wide range of shapes. Consequently, flexible distributions such as beta distribution is required to properly fit the diversified characteristics of such data. Statistical distributions are also widely applied to other aspects of construction project performance. Tam et al. (2008) [16] used Gaussian and hyperbolic distributions for quality improvement in construction. Furthermore, Touran and Wiser (1992) [17] used data from building projects and demonstrated that lognormal distribution fits project cost data better than other distributions.

Among numerous efforts, the applicability of Weibull analysis to the evaluation of schedule performance has also been addressed in the last decade. Weibull analysis is a technique that consists of fitting the Weibull distribution to a set of data representing a certain characteristic of a system and then analyzing reliability of the system based on the fitted distribution. The Weibull distribution has been widely used to model data with high degree of variability in a various fields, including failure analysis and reliability engineering. It is also called as Weibull analysis. The Weibull function is a probability distribution function (PDF) that takes a number of different shapes, depending on its parameters.

Although Weibull analysis may have many potentials for schedule performance prediction, its application to construction projects has been limited so far. Nassar et al. (2005) [7] demonstrate the applicability of Weibull analysis for evaluation of schedule performance in multiple projects by fitting the Weibull distribution to monthly calculated cost and schedule performance indices. Hence the more application of Weibull analysis is needed for construction projects especially in our nation. Next section consist of detailed discussion on EVM

III. EARNED VALUE METHOD

The Project Management Institute [2] defined EVM as a management methodology for integrating the project's scope, schedule, and resources, and for objectively measuring project performance and progress from project initiation through closeout. EVM relies on three basic performance variables earned value (EV), actual cost (AC), and planned value (PV), to evaluate where a project is and where it was supposed to be. The schedule variance (SV), schedule performance index (SPI) are used for schedule analysis. The cost variance (CV) and Cost performance index (CPI) are used for cost analysis. Basic elements of EVM analysis described below in the Fig. 2

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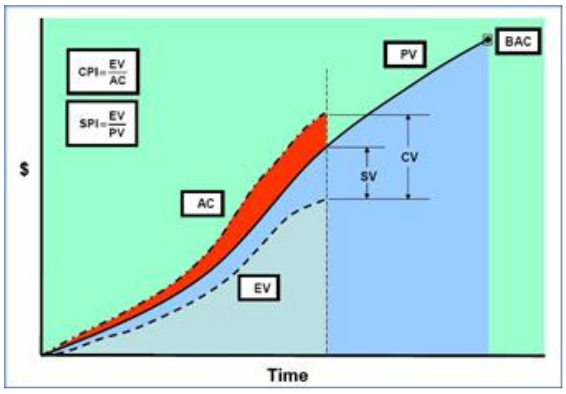

Description of Basic EVM Elements

Planned Value (PV): The cumulative planned cost for the work planned to be done on the project up to a given point in time. It is the approved budget for completing the work planned so far, and as such it is the cost baseline for the project. It was previously called the budgeted cost of work scheduled (BCWS). Budget at Completion (BAC): The total amount of money expected to be spent on the project, and as such it is the value that PV is planned to reach at completion.

Actual cost (AC): The cumulative actual cost spent on the project so far, including all accrued cost on the work done. AC was previously called the actual cost of work performed (ACWP).

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Earned value (EV): The cumulative amount of work done up to a point in time, expressed in cost units. It is expressed as the amount that was planned to have been spent on the work that has been completed up to this point. EV was previously called the budgeted cost of work performed (BCWP). To calculate the EV for a given element of work, the planned cost is multiplied by the percentage complete. The EV for the project is the sum of the EV for all the work elements. BAC, PV, AC and EV are expressed in cost units. That may be in units of actual money, in any currency. Or it can be expressed in hours or days of work done. PV, AC and EV can be calculated for any element of work to determine progress on that element of work. There are two basic data elements in the EVM report that are central to proper planning, measurement, and analysis: budgeted cost of work scheduled (BCWS) and actual cost of work performed (ACWP). Nearly all of the other data items in EVM may be derived from these three data items. Two important performance indices are CPI and SPI. The indices are ratios. During project execution, CPI and SPI provide information about performance efficiency. CPI is the efficiency of achieving EV with respect to the actual costs (CPI=BCWP/ACWP). SPI is the efficiency of achieving EV with respect to the performance baseline (SPI=BCWP/BCWS). In the above-presented formulas, 1.00 indicates that performance is on target. More than 1.00 indicates excellent performance; and less than 1.00 indicates poor performance. In practice, the warning level is generally drawn at 0.90. When the index drops to between 0.90 and 1.00, more intensive monitoring measurements need to be taken. When the index reaches below 0.90, corrective actions need to be taken to avoid losing control of the project [19-20].

IV.WEIBULL DISTRIBUTION

Weibull distribution is named after Walodi Weibull (1887 – 1979). It is widely used method in the field of manufacturing and industrial engineering. Weibull analysis is mainly used for simulating failure rates or lifetime of certain product. By using this analysis one can forecast the future about product's life, compare the reliability of competing product designs, and manage spare parts inventories to name a few common industrial applications [21-22].

This distribution can be found with two or three parameters; scale, shape and location parameters. 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.

Weibull distributions come in two and three parameter variants. A third parameter can be successfully used to describe failure behavior 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 pdf equation reduces to that of two parameter Weibull distribution. There is also a form of the Weibull distribution known as the one parameter

As was mentioned previously, the Weibull distribution is majorly used in reliability and life data analysis due to its versatility. The Weibull distribution can be used to model a variety of life behaviors depending on the values of the parameters. A major aspect of the Weibull analysis 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 [1].

The Weibull shape parameter, β, is also called as Weibull slope due to the value of β is equal to the slope of the line in a probability plot. Different values of the shape parameter can have effects on the behavior of the distribution. Some values of the shape parameter resulted in 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. 3 shows the effect of various values of the shape parameter, β, on the shape of the pdf (while keeping γ constant).

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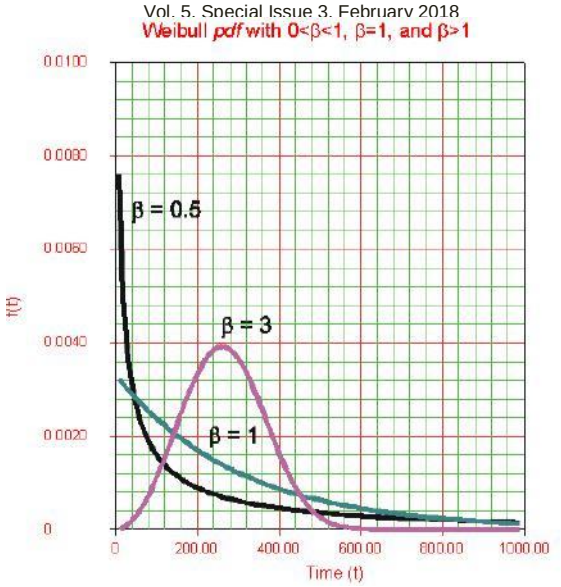

Fig. 3. Weibull distribution with different scale parameter. [1]

In summary, following are the advantages of using the Weibull distribution:

1. It has been found to accurately model quality and performance characteristics and its affability that makes it ideal for analysis on a dataset with unknown distribution.
2. The parameters α and β represent a meaningful measures to the task at hand.
3. It contributes risk predictions and accurate failure analysis with small samples.

Once the considered characteristic is fitted to the Weibull distribution, the risks associated with the system, like the probabilities of meeting specific performance or quality levels, can be measured and analyzed. Therefore, the application of the Weibull analysis to the EVM entails fitting cost and schedule performance indices data of the project to the Weibull distribution and then analysing the schedule and performance along with the risks involved.

IV. SIGNIFICANCE OF STUDY

Construction industry is important sector for economic development of nation. This industry majorly contributes in area of improvement of GDP. Hence, both public and private sectors invest money in this industry. Still in this, large amount of money are lost each year because of poor management, poor schedule and cost control. There are various agencies involved in executing construction projects such as government contractors, consultants etc. Few of these agencies have their own systematic schedule monitoring and controlling systems. Earned Value Method (EVM) is use to control and monitor cost and schedule performance traditionally. EVM is considered as an accurate tool that supports management systems of project. However, this traditional EVM may cause some project managers to ignore the information it can provide the value of β

EVM is a deterministic method which requires some probabilistic and statistical approach for more precise results. The research conducted focuses on the evaluation this traditional cost and schedule performance technique that is nothing but EVM. In this study the limitations of EVM are discussed and highlighted on the various EVM based schedule forecasting methods. Moreover presents statistical approach in form of Weibull analysis to evaluate the performance of construction project. The study aims broadly over the applicability of Weibull analysis for evaluating and comparing the performance of construction project.

Initial section of this study briefly covers review on various research regarding conventional EVM and performance indices, cost and schedule performance indices also limitations of EVM. The second half of study consist of review on Weibull analysis and its application to EVM

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VI. SUMMARY AND DISCUSSION

In Every, Project the Timely Completion is of prime importance and thereby keeping the projects on track, monitoring progress of design and construction projects by controlling schedule and cost.

EVM technique is traditionally used for monitoring and controlling construction projects by calculating C/SPI.

This paper consist of review on conventional EVM method and its limitations further, it highlights Weibull distribution for probabilistic analysis of C/SPI and it is concluded by reviewing this paper that, the Weibull analysis is very flexible and effective technique for analyzing cost and schedule performance indices and making decision about managing the projects.

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