Review of Available Schedule Management Approaches

Tzu-Hua Lai and Jyh-Bin Yang

***Abstract*—Schedule management is important when conducting a project because poor schedule management might increase the cost and sometimes decrease the quality of the project. Since there are lots of distinct means of schedule management, this paper only focuses on earned value management (EVM)-based method and its extensions. The superiority of EVM is that it combines the concepts of scope, quality and cost. Also, it can forecast final duration and monitors the performance of a project along its progress. As construction projects become more complicated, EVM turns out to stand out over other methods. EVM methods have been tested and simulated in many literatures. However, a user still encounters the problem of selecting suitable methods. The purpose of this article is to review EVM-related methods and to summarize basic principles for selection. The research results could be a guide for EVM-related methods selection and the basis for future research.**

***Index Terms*—Earned duration, earned schedule, reference class forecasting, XSM.**

I. Introduction

Among a variety of ways to manage project schedule, earned value management (EVM) presents well in forecasting final duration and monitoring project performance. The research about EVM methodology has been conducted last for decades, and project managers have started to choose EVM rather than traditional project control techniques for practical cases. Though there are already exist a lot of researches about EVMs and their comparisons, as innovative methods and new ideas appears, the comparisons seem to be segmented and incomplete. As a result, this article is going to review some researches about EVM in order to provide basic information for future comprehensive and integrated studies.

II. Earned Value Management

A. Review Stage

In 2005, Stephen Vandevoorde and Mario Vanhoucke reviewed literatures and information from the past, then they gave an overview of the state-of-the art knowledge for the new research trend to bring clarity in the often confusing terminology at that time [1]. Also, they compared performance index of earned value and earned schedule, which are schedule variance (SV), schedule performance index (SPI) and Schedule variance for time (SV(t)) and Schedule performance index for time (SPI(t)). Moreover, a generic schedule forecasting formula is presented, which could be applied in different project situations. One of the research result is that, among three real-projects, only earned schedule method showed the satisfying and reliable outcome during the whole project duration [1].

About three years later, Vanhoucke and Vandevoorde presented a simulation study with new simulation scenarios that measure the influence of inaccuracies in the planned duration estimates for critical and non-critical activities on the accuracy. That research presents the power of earned schedule (ES) value through using accurate ES value and inaccurate ES value to forecast estimate at completion (EAC(t)). And the result shows that under normal circumstances, earned schedule management (ESM) method can be a reliable forecast tool [2].

It is always a trouble for researcher to prove their ideas or concepts are right if there is no complete and reliable database. Fortunately, a real-life project database was then created which could be outranking any other existing empirical databases. To guarantee the quality and correctness, a database construction and evaluation framework based on the so-called project cards was developed [3]. A project card tells the specifics of a certain project and provides a tool for categorizing and evaluating these project data. It is worth mentioned that project cards include the dimensions of dynamic scheduling, project authenticity and tracking authenticity.

To assess the accuracy of the most commonly used EVM forecasting for both time and cost based on a large and diverse real-life project database is the main purpose of another research [4]. The database which was chosen is database developed by Bastelier and Vanhoucke [3]. According to the circumstances, ESM with performance factor (PF) equal to one (PF=1) shows the best result, for both overall accuracy and timeliness. Nevertheless, ESM with PF of 1 or SPI(t) still proves its value higher than planned value management (PVM) and earned duration management (EDM) approaches. This paper also discusses the impact of project seriality on time forecasting accuracy and found out that as serial/parallel index (SP) increase, the forecasting accuracy also increase.

Preliminary comparison of three duration forecasting techniques, which are the earned value management (EVM), earned schedule management (ESM), earned duration management (EDM), has been made. More specifically, two respectively integrated rework and activity sensitively in EVM time forecasting as extension was set up. Under the conditions that authors set, ESM with PF=1 performed the best not only over the entire project, but also for every specific completion stage [5].

Kahneman and Tversky [6] and later Lovallo and Kahneman [7] introduced a method which calls reference

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class forecasting (RCF) in order to overcome the inaccurate forecasts cause by human bias. After that, Jordy Batselier and Mario Vanhoucke [8] conducted an evaluation based on a real-life database and proves that RCF outperforms Monte Carlo simulation and even EVM when using reference class forecasting (RCF) for construction project time forecasting.

According to the outcomes by Jordy Batselier and Mario Vanhoucke [9], when integrating EVM with the exponential smoothing forecasting approach, there was a new time forecasting method which called XSM. XSM can also incorporate into RCF, and exhibits an obvious overall performance improvement at project forecasting accuracy result from 23 real-life projects.

A new concept of EVM was developed by Chia-Jui Chang and Szu-Wei Yu [10]. Instead of only considering two dimensions of a project, the new approach which considers cost, scope and schedule was introduced. The newly developed means is named earned time method (ETM). Also, the study investigated about the relationship among cost, time, and work. Further then recommended to add an independent performance measure, work variance (WV), when dealing with EVM.

B. Earned Value Management System

Before starting to discuss those of the complicate research results, it is necessary for us to provide a brief overview of EVM's basic but key metrics, formulas and their definitions.

- Actual time (AT): the current time
- Planned value (PV): according to the project plan, the expected value that should have been finished at the actual time
- Earned value (EV): according to the project plan, the actual value that could have been earned at the actual time
- Actual cost (AC): the actual cost that have been incurred at the actual time
- Earned schedule (ES): according to the project plan, the time at which the EV should have been earned, $ES = t + \frac{EV - PV_t}{PV_{t+1} - PV_t}$ whereas t is the point in time for which $EV \geq PV_t$ and $EV < PV_{t+1}$ [11]
- Schedule variance (SV): $SV = EV - PV$
- Cost variance (CV): $CV = EV - AC$
- Work variance (WV): $WV = EV - PV$
- Schedule performance index (SPI): $SPI = \frac{EV}{PV}$
- Cost performance index (CPI): $CPI = \frac{EV}{AC}$
- Schedule variance for time (SV(t)): $SV(t) = ES - AT$
- Schedule performance index for time (SPI(t)): $SPI(t) = \frac{ES}{AT}$
- Schedule cost index (SCI): $SCI = SPI \times CPI$
- Schedule cost index for time (SCI(t)): $SCI(t) = SPIT(t) \times CPI$
- Percentage complete (PC): at the activity level, it stands for the percentage of the work that completed
- Performance factor (PF): expresses either cost or schedule performance of the project
- Estimate to completion for time (*EAC*(*t*)): the prediction of the final project duration

$$EAC(t) = AT + \frac{PD - ES}{PF} \quad (1)$$

PF in the equation of *EAC*(*t*) represents the assumption of the future project performance. In other word, if we assume *PF*=1, that means we suppose the future project performance is going to be according to the original plan. On the other hand, if we assume *PF*=*SPI*, that shows we presume future performance of the project is identical to the present project performance. Fig. 1 shows the relationship of main metrics in EVM.

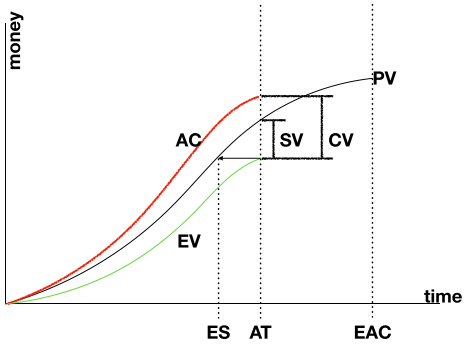

Fig. 1. Relationship of main EVM metrics.

C. Evaluation of Forecasting Accuracy

The most common method to evaluate forecasting accuracy in earned value management relative literatures is mean absolute percentage error (*MAPE*), the formula is shown in following:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A - P_t}{A}\right| \quad (2)$$

A: Actual value at the end of the project
P_t: forecasted value at tracking period t
n: the number of tracking period

The smaller the *MAPE* of a considered forecasting method, the higher the accuracy of the method possesses.

III. Comparisons of Available Schedule Management Approaches

According to literatures review in the second part, there are two more topics that should be concerned in order to produce our research results. First of all, the advantages and disadvantages throughout the EVM methods (Table I). After that, applicable conditions of the relative methods will be mentioned.

A. Advantages Versus Disadvantage

Estimating final duration is one of the important functions of EVM relative methods. Managers can administrate the project by the information. Abilities of monitoring progress and warning at the project's early stage also make EVM outperform traditional schedule management methods. However, there are also some disadvantages that may cause people choose other measures instead of it. Complex calculation is one of the well-known reasons, but it is not the only one. Another important shortcoming is that SPI always equals to 1 at the end of the project. The result has a great possibility of being irrespective of the actual performance,

which leads to the appearance of ESM.

Inheriting all the advantages of EVM as Table I shows, ESM holds its superiority over EVM by offering reliable SPI at the end of the project. Nevertheless, due to monetary-based characteristic, similar to EVM, ESM manifests high dependent on correspondence within time and cost profiles of the project. In another word, the higher the disparity between time and cost profiles of a project, the more inaccurate the schedule performance offered will be [12]. As a result, when an inexpensive activity happens to be delayed a lot on the critical path, SPI(t) will result in incorrect information.

EDM then shows its natural merit of being a time-based measure. According to the research by Homayoun Khamooshi and Hamed Glolagshani [12], EDM concludes all advantages of both EVM and ESM methods. The only issue that might be classified as a disadvantage is its complicated calculation. The *EAC*(*t*) formula is show in Equation (3), in which *PD* is planned duration and *DPI* is duration performance index.

$$EAC(t) = \frac{PD}{DPI} \tag{3}$$

When using the formula of equation (3), it can achieve quite accuracy of forecasting that can fairly compare with ESM method [5]. Regardless of choosing either EVM, ESM, or EDM, there are always chances that taking use of metrics schedule variance (SV). However, as everyone knows, there exists some problems when using it. When SV equals to zero, it might imply that the ongoing project is on schedule, but it could also mean that the project is completed. Thus, it shows the benefit of utilizing ETM that provides work and time performance status of the project respectively, especially when the project is overdue [10].

RCF is a schedule management method that can also provide estimation for project duration. Despite RCF only generate a static prediction, it can overcome human bias. Human judgment is often too optimistic due to overconfidence and insufficient of actual previous experiences [8]. Noted there is another disadvantage, the accuracy of this method depends very much on the degree of similarity between the considered project and the projects in the reference class from the database.

Exponential smoothing-based method (XSM) is an extension of EVM methodology. As well as EDM, XSM inherits the advantages of EVM and ESM. Moreover, it expresses the most accurate of *EAC*(*t*) forecast. Though XSM has great potential in schedule management, it is difficult to make use of its full capacity.

B. Applicable Conditions of the Relative Methods

Factors that affect the results of EVM relative methods are complicated and hard to recognize all of them. Different project conditions will lead to different suitable method. Researchers have already started to distinguish them and this study now attempts to summarize them by literatures that have been mentioned above. Table I shows the advantages and disadvantages for discussed EVM relative methods.

Single-activity project can be divided into two categories, planned value which displays in linear and planned value which is non-linear. The former can be considered as project without the presence of learning curve, whereas the latter means learning curve factor exists. Linear project case shows similar results based on planned value management (PVM) and ESM except for the EDM method with a SCI trend. On the other hand, in the considered example, non-linear project case which is much more possible to happen in realistic world shows ESM method results in longest duration. When forecasting at project level, we can first categorize projects into three types (Table II): behind schedule with under cost, behind schedule with over-run cost, and ahead of schedule with over-run cost. SPI sand SPI(t) correlate well at the beginning and middle stage in project type 1, though SPI becomes unreliable toward late project stage. Also, in project type 1, PVM method starts to provide strange and inaccurate forecast as long as the project time has reach the planned time at completion. ESM method outperforms in both project type 1 and type 2, also it remain better forecast till the end of the project. Type 3 shows that traditional earned duration and planned value rate will cause longer duration which will lead to wrong decision-taking. As a result, ESM is the only one that shows reliable result during the whole project [1].

TABLE I: ADVANTAGES VERSUS DISADVANTAGES

Method	Advantages	Disadvantages
Earned Value Management	1. EAC forecast 2. Monitor progress 3. Warn at the early stage	1. Complex calculation 2. Monetary-based measure 3. SPI eventually approach to 1
Earned Schedule Management	1. EAC forecast 2. Monitor progress 3. Warning at the early stage 4. Honestly reflect the schedule performance till the end of the project	1. Complex calculation 2. Monetary-based measure 3. Overshadow large delays of inexpensive activities on the critical path
Earned Duration Management	1. EAC forecast 2. Monitor progress 3. Warn at the early stage 4. Time-based measure	1. Complex calculation
Reference Class Forecasting	1. EAC forecast 2. Easy calculation 3. Show high accuracy of forecasting 4. Overcome human bias	1. Recommend high similarity of project database 2. Lack of ability to monitor progress and warn in the early stage
Exponential Smoothing-based Method (XSM)	1. EAC forecast 2. Monitor progress 3. Warn at the early stage 4. Demonstrate the highest accuracy among these methods	1. Complex calculation 2. Difficult in make use of the full potential of the XSM

We can also categorize project in another kind of four scenarios (Table III). In scenario 1 and 2, ESM outperform EVM and EDM methods. ESM expressed better forecast accuracy close to 0%. However, ESM displayed terrible estimation and was even worse than PVM and EDM. Such a huge change results from the power of schedule indicator SPI(t). That implies a fact that the forecast accuracy is highly

depend on the reported SPI(t) values along the life of the project. Which means, under normal circumstances, defined as project progress can report reliable schedule performance index, the earned schedule can be considered as a good forecast predictor [2].

TABLE II: THREE PROJECT TYPES

Method	Over time in budget (type 1)	Over time over budget (type 2)	In time over budget (type 3)
Planned value management	Present strange forecast when reach the PAC	Unreliable at late project stage	Unreliable at late project stage
Earned schedule management	Outperforms especially at the last stage	Outperforms especially at the last stage	Outperforms especially at the last stage
Earned duration management			Become pessimistic at the late stage

TABLE III: FOUR SCENARIOS FOR CRITICAL AND NON-CRITICAL ACTIVITIES

Scenario	Critical activities	Non-critical activities	Ahead or delay?
1	Decrease or no change	Increase or no change	Project ahead of schedule
2	Increase or no change	Decrease or no change	Project delay
3	Decrease	Increase	Project ahead of schedule
4	Increase	Decrease	Project delay

There are two more characteristics which are timeliness and project seriality. Beside overall accuracy, timeliness is also an essential evaluation criterion for schedule forecasting methods [4]. The accuracy of forecasts relies on the timeliness, completion stage of the project. Completion can be categorized into three group according to percentage complete (PC):

- Early stage: 0% ~ 30%
- Middle stage: 30% ~ 70%
- Late stage: 70% ~ 100%

PC can be calculated by EV/BAC, where BAC represents budget at completion. It has found that the seriality can affect the preciseness of the forecasts. Project seriality can portray the project's network structure through by means of telling how close the network is to a serial or parallel network. Serial/parallel (SP) indicator which ranges from zero to one can represent the seriality.

$$SP = \frac{n_s - 1}{n_t - 1} \quad (4)$$

n_s: maximum number of subsequent activities in network

n_t: total number of activities

In order to research further, *SP* is categorized into three groups too:

- Parallel projects: 0% ~ 40%
- Serial-parallel projects: 40% ~ 60%
- Serial projects: 60% ~ 100%

When doing forecasting over all projects in the database, ESM with performance factor equals to one (ESM-1) shows its dominated status. In addition, it is authentic for both simulated and real forecasting. Under the best forecast method, the second is not identical for simulation and real forecasting. Unweighted methods, which are methods with PF equals 1, hold the secondary precision in real forecast, whereas ESMs hold second place in simulation. The main reason for unweighted methods showing high accuracy, which is different from previous research, is probably because ESM-SPI and ESM-SPI(t) take into account of possible corrective actions made by management purpose. For seriality evaluation, it is found that when forecasting accuracy increases, the degree of seriality increases both of them.

EVM can also integrate with two more characteristics, rework and activity sensitive. It is possible to consider of rework by adjusting earned values. The formula that is able to quantitative rework is showing below:

$$R = \left(1 - PC^n \times e^{-m(1-PC)} \times (1 - P) \times EV\right) \quad (5)$$

In Equation (5), P (*p*-factor) demonstrates the degree of schedule adherence. When *P* is equal to 0, it means there is no schedule adherence. *N* and *M* are usually respectively set to be 1 and 0.5, yielding an approximately linear decrease of the rework fraction when the percentage complete (*PC*) increases. Hence, adjusted *EV* can be calculated as Equation (6) and *ES*(*e*) can be calculated by *EV*(*t*).

$$EV(e) = EV - R \quad (6)$$

Activity-based sensitivity measure is used with weighing parameter for the planned value and earned value of the activities. The intension is result from accuracy improvement caused by removing or decreasing the negative effect of wrong warning signals made by non-critical activities. In the article, the author chose to make use of critically index (CI) to assess sensitivity.

Identical to the upper research [4], earned schedule method with performance factor equals to one (ESM-1) without extension shows the highest accuracy. Again, the dominance of ESM-1 exists is assumed – implicitly consider potential corrective action performed by management in order to improve lagging project performance [5].

It is interesting that combining two extensions, rework and activity sensitivity will not produce more accurate than the original ESM method. Table IV presents the accuracy comparison results.

Nevertheless, noted that there is a positive potential when integrating only rework with ESM-1. On the other hand, it turns out to be disadvantageous when combing activity sensitivity index to ESM-1. Oppositely, performance-based methods, such as EDM with PF equals to DPI (EDM-DPI) and ESM with PF equals to SPIT(t) (ESM-SPI(t)), are able to improve their forecast accuracy through integrating with activity sensitivity concept whereas showing poor result when integrating with rework. Despite that, the extension of sensitivity primary happens in early stage of the project.

There are two approaches for XSM which are static and dynamic. The only one parameter of XSM is ß and there are five values of it, as Table V shows [9]. Both XSM with $ß_{opt,rc}$ and RCF need a database that contains high degree of similarity of historical project data. The more the degree of similarity, the more the forecast accuracy can be improved.

TABLE IV: ACCURACY COMPARISON OF TWO EXTENSIONS

extension	ESM-1	ESM-SPI(t)	EDM-DPI
None	The most accurate	-	-
Rework	Accuracy improved	-	-
Sensitivity	-	Accuracy improved	Accuracy improved
Both	-	-	-

TABLE V: ACCURACY COMPARISON OF TWO EXTENSIONS

Variable	Approach type	Explanation
ß	Static	General smoothing parameter Assume ßis chosen before the project start and will remain till the end
$ß_{opt}$	Static	The optimal value for ßof a certain project in the database
$ß_{opt,oa}$	Static	The optimal value for ßover all project in the database
$ß_{opt,rc}$	Static	The optimal value for ßover all project in the database with in a same reference class
$ß_{dyn}$	Static	The variable smoothing parameter value that is calculated over every tracking period

IV. DISCUSSION

Ideas of the most accurate method has changed over years. In those early literatures, ESM with PF=SPI(t) was considered to be the most accurate forecasting method. But after conducted simulations and testing in real project database, it turns out that performance factor equals to one (PF=1) really outperforms. Moreover, innovative methods are rising, such as reference class forecasting (RCF), exponential smoothing method (XSM) and earned duration method (EDM) with new PF also show great potentials for schedule forecasting. This study believes that some innovative methods would be proposed soon to attack shortcomings of existed schedule management methods.

Undoubtedly, timeliness is an essential characteristic that should be concerned in addressing schedule management methods. Forecasting accuracy has to maintain at a certain level all along the project life. Early stage of the project can be considered as a key period. If we received the scheduled warning at the early stage, corrective decisions could be made in the first place to reduce the loss and damage. Also, seriality is likely to have an impact on precision. The more the seriality of the project network is, the forecast becomes more accurate. Rework and activity sensitivity should be taken into account too, yet need to notice the possible effect of using them simultaneously. Number of the tracking period might also make slightly difference to the forecasting result. Above information implies to select a suitable method or multiple methods is necessary and will be conducted in near future.

In addition, database that contains historical project data is getting more important. The technique of RCF is highly depended on the quality of the database. Though setting up a database might cost additional effort, but the benefit that it could feedback is definitely worth it. XSM with $ß_{opt,rc}$ thus provides reliable forecasting result that could compare with earned schedule method. How to develop a useful database would be another essential issue for project management and schedule management teams.

V. CONCLUSION

The main purpose of this paper is to review the schedule management approaches from recent researches. Today, construction projects have the sign of getting more and more complex. Therefore, EVM methods are prevailing due to its comprehensiveness. Since the techniques of calculation and measurement are keep evolving, there are necessity of to sort out a guide that helps giving the idea of which method to employ.

According to the research review, this study attempts to give an overview in order to present a basic principle for choosing the suitable method. Generally, it is suggested to select ESM-1, ESM-SPI(t), or EDM-SPI(t) to manage schedule and give forecasts for all life cycle of the project. If a schedule manager chooses the performance-based method, which is the latter two methods, using ESM-1 to double check the forecasting and monitoring results at the early stage would be a wise thing to do. Furthermore, if a schedule manager would like to take into account of other factors, seriality, rework, and activity sensitivity are the characteristics that can be picked. As for seriality, increasing the degree of project seriality is going to meanwhile increasing the accuracy of the forecast. Supposed the project wants to put rework into consideration, ESM-1 might be the preference choice. And when it comes to activity sensitivity, performance-based methods would be the better selection, which are ESM-SPI(t), EDM-SPI(t). There is one more last thing that needs to be reminded. It is not recommended to choose rework and activity sensitivity at the same time to increase the precision, the effect will only diverse.

There are lots of details that should take care of if a schedule manager wants to make use of EVM and its extension to conduct a perfect schedule management of a project. Therefore, it is necessary to test the usability and stability of those EVM methods with real projects. Factors that mentioned above should be considered depends on the needs.

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