

# BIM-Based Time and Cost Tracking of Construction Projects Taking Quality Management into Consideration

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**Abstracts:** The construction industry has long suffered from the lack of time and cost tracking systems that take the impact of quality issues into account. Accordingly, emphasizing the integration of Earned Value Management (EVM) and Building Information Modeling (BIM) taking quality management into consideration has become a crucial requirement. The main objectives of this study are to address quality management into BIM and enhance monitoring of project's time and cost performance via addressing the effect of quality issues in order to support making the proper decisions to restore the original plan's progress. Using the capabilities of Application Programming Interface (API) and C# as a powerful programming language, this enhancement is achieved by the development of a BIM-based model including three plugins: Bill of Quantity (BOQ) estimator, Quality inspector, and EVM controller. BOQ estimator tool includes data about element's ID, the corresponding category, geometric properties and the corresponding cost details. Quality inspector tool includes, for project activities as well as elements making up each activity, the related most recent quality status from on-site records. On the other hand, EVM Calculator tool represents the core of the mathematical model that includes planned/budgeted data, actual data and results of EVM analysis providing performance indices and cost/time variances. In this paper, authors focus on providing details about the mathematical model developed to implement EVM Calculator tool via combining the effect of task's quality status on EVM variables. The proposed mathematical approach is validated using four different simulation scenarios. Results of the proposed model were compared with those obtained (and then revised to reflect the effect of quality status on task's/project's time and cost) using primavera P6. The results on comparison show the efficiency of the developed model providing an opportunity to address the effect of quality issues into EVM analysis that would reduce calculation time and eliminate chances of human errors associated with altering of results.

**Keywords:** Building Information Modeling, Earned Value Management, Quality Management, Time-Cost Tracking.

## 1. INTRODUCTION

Many of the Architecture, Engineering, and Construction (AEC) projects are seem to be often large and complex, alongside with many stockholders involved with the decision process. For all of the previous, quick and automotive tools should be used to facilitate all the pre-mentioned obstacles (Ribeirinho et al., 2020). Using BIM technology is no longer an option rather than it is a mandatory pillar to achieve effectiveness, and efficiency. BIM is a digital representation for an asset that might be a building or an infrastructure project, which can be used in a variety of purposes that are called BIM uses. These uses demonstrate how we can harness BIM capabilities to achieve the project goals such as project planning, scheduling, cost estimating, clash detection, document management, life-cycle management, etc. (Boton et al., 2015). A 2016 McKinsey analysis (Ribeirinho et al., 2020) found that construction projects typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget, frequently resulting in litigation. That often leaves customers dissatisfied, resulting in complex and time-consuming claims processes. Moreover, at 2019, the Construction Industry Institute showed that a schedule delay can hit more that 30% of the construction projects in US regions (Ribeirinho et al., 2020). These statistics represent a wrong sequence of factors and decisions made during project execution such as inaccurate cost estimation, change in project scope, poor planning and scheduling, and underestimate forecast capabilities. For these reasons, using BIM as a 3 dimensional digital representation is not enough to satisfy the market needs. As a result, several studies highlighted the best practices to implement 4 Dimensional BIM-based models via adding dimension of time and scheduling information to the 3D model (Crowther & Ajayi, 2021; Elghaish & Abrishami, 2020; Jin et al., 2019; Sloot et al., 2019). In addition, 5D BIM is generally considered to be adding cost information to a model. Several studies focused on how to construct a 5D model to perform model schedules, planning, and cost estimation (Kehily & Underwood, 2017; Moses et al., 2020; N.hasan & Rasheed, 2019; Smith, 2016). Others established a study on how to deliver a

successful coordination procedure between all the building components (Jrade & Lessard, 2015; Tatum & Korman, 1999). Furthermore, in some cases the clash detection process was considered to be the main purpose of the model, hence how to establish an easy, solvable, and readable clash matrix was the main goal especially for time-space conflict (Miyagawa, 1997).

In the same context of improving BIM-based models, combining BIM technology and EVM technique would provide the model with further insights that can help project managers to avoid an upcoming issue, maintaining current progress rate, or take a corrective action in the current stage. Several studies focused on applying EVM technique on one or more case studies with highlighting the main advantages of EVM implemented in a BIM-based model. Adopting EVM technique, researchers have proven that significant enhancements can be achieved such as, completion prediction, taking progress and human risk into consideration, and introducing the progress indicators (Cárdenas et al., 2018.; Elghaish et al., 2019; Kenley & Harfield, 2015.; Moses et al., 2020). Despite these benefits, the number of studies available clearly shows that few investigations were conducted to integrate BIM concept with EVM features without unleashing the full potential of such integration through insufficient real case studies (Elghaish et al., 2019).

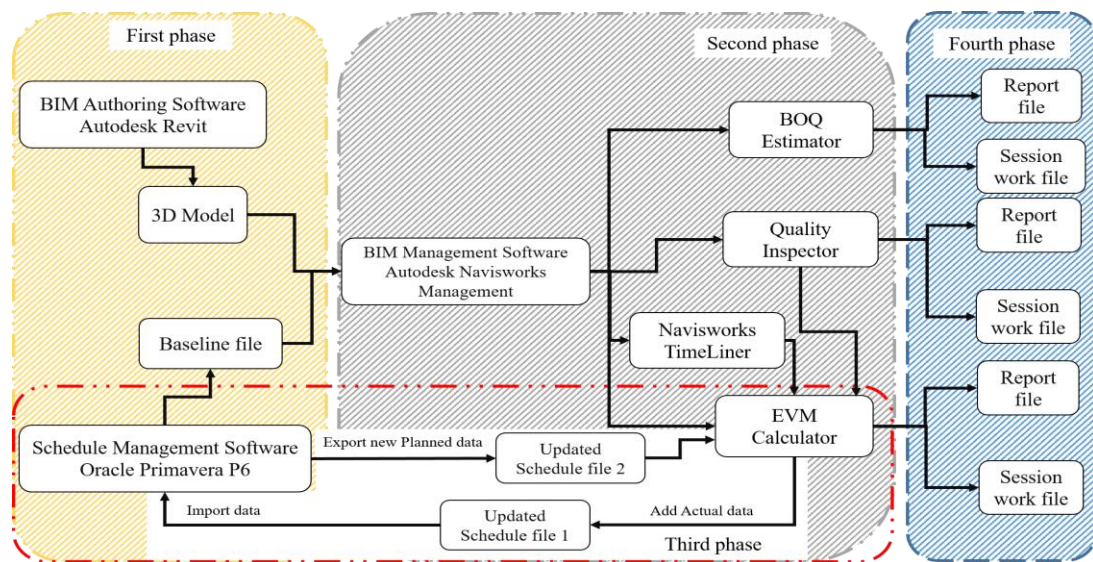
On the other hand, studies based on the integrated application of BIM and construction quality management represent a significant development for comprehensive BIM-based models. Some studies are based on constructing a data definition structure for all elements in the BIM-based model to combine quality data and quality control processes into the proposed model (Choi et al., 2020; Park & Kim, 2015). Other studies adopted an integrated application of BIM and Global Positioning Systems/Indoor Positioning Systems (GPS)/(IPS) technologies. The main objective of these studies, for the corresponding elements in the BIM-based model, is to automate the processes of generating the inspection tasks, collecting the inspection data, and summarizing the inspection results (Asadzadeh et al., 2020; Reinbold et al., 2019).

It should be noted that, studies concerning the development of BIM-based models and combining the effect of quality issues on EVM variables are very rare. In one of the recent studies (Project Management Institute., 2008), authors presented a quality-embedded EVM tool to facilitate monitoring of schedule, cost and quality. They recommend integrating construction quality management and EVM with BIM technique.

This current study aims to address quality management into BIM and enhance monitoring of project's time and cost performance via addressing the effect of quality issues on EVM variables. This enhancement would help project managers to make the proper decisions to restore the original plan's progress. To this end, a BIM-based model is developed including three plugins: Bill of Quantity (BOQ) estimator, Quality inspector, and EVM controller. Structure of the proposed model and functions of each component are presented in the next section.

## **2. STRUCTURE OF THE PROPOSED MODEL**

To achieve objectives of this study, the study has developed a BIM-based model employing two BIM software packages from Autodesk: Revit and Navisworks. In addition, the Primavera P6 software is used for project scheduling throughout its lifecycle. In the proposed model, there are four major phases as shown in Fig. (1).



**Figure 1:** Structure of the Proposed Model

In phase (1), using Autodesk Revit, detailed model-based 3D design of the project at hand is created. On the other hand, Primavera P6 is mainly used to develop the corresponding project schedule. However, P6 is utilized to assign resources and indirect cost to project activities which then allow users to ensure that cost estimates match those provided by the developed "Bill of Quantity (BOQ) estimator" plugin. It is important to point out that Primavera P6 is employed once more in phase (3) to perform schedule update based on the project actual data and work progress. The main deliverables of phase (1) are the project 3D design and baselines for the project schedule and cost.

Phase (2) represents the core of the proposed model. In this phase, Navisworks is adopted to take advantage of the potential to integrate the 4th and 5th dimensions, by including time frames and costs. In this study, Navisworks is employed to host three plugins: BOQ estimator, Quality inspector, and EVM controller. BOQ estimator tool includes data about element's ID, the corresponding category, geometric properties and the corresponding cost details. Quality inspector tool includes, for project activities as well as elements making up each activity, the related most recent quality status from on-site records. On the other hand, functions of EVM Calculator tool are shared between phase (2) and phase (3). In phase (2), in addition to Navisworks time frame labelled as 'TimeLiner', EVM Calculator tool represents a store for planned/budgeted and actual records. Using these records and the most recent status of quality updates provided by Quality inspector, EVM Calculator tool - in phase (3) - performs EVM analysis providing results of performance indices and cost/time variances.

Phase (3) represents the core of the mathematical model to reflect the effect of quality issues on the project schedule and cost. Utilizing P6 for scheduling purposes, forecasting the final total duration and cost of the project is effectively achieved adopting the developed algorithm conducted by the EVM Calculator tool. Details about the mathematical approach proposed in this study are presented in the next section.

In phase (4), for each plugin, two types of files are created to store intermediate and final results/records. Results of incomplete work session can be saved in files labelled as 'Session work file' to complete later in another session. On the other hand, final results are saved in files labelled as 'Report file'. This option enhances the capabilities of the proposed model to share results/records with all key internal and external stakeholders.

### 3. THE PROPOSED MATHEMATICAL APPROACH FOR EVM IMPLEMENTATION

In this paper, authors focus on providing details about the mathematical model developed to implement EVM Calculator tool via combining the effect of task's quality status on EVM variables. General background on EVM, general considerations taken into account for the proposed mathematical approach, and means of integrating the proposed mathematical approach with task's quality status are, respectively, presented in the next subsections.

### 3.1. General Background on EVM

Earned value management (EVM) in its different forms is a popular approach of measuring performance. It incorporates project scope, cost, and schedule metrics to aid project management team to evaluate and measure the project's performance and progress. It represents a method of project monitoring via establishing an integrated baseline against which performance may be assessed. According to Project Management Body of Knowledge (PMBOK) [22], EVM For each work package and control account, creates and monitors three important parameters as shown in Fig. (2): planned value, earned value, and actual value.

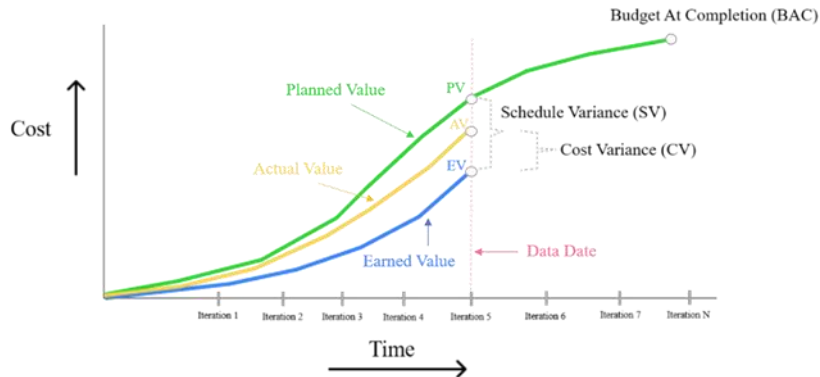


Figure 2: EVM Chart

- Planned value: Planned value (PV) is the amount of money that has been authorized and has been allocated to the task at hand for a particular activity or Work Breakdown Structure (WBS) component. Accordingly, planned value (PV) is the planned progress multiplied by the approved budget at completion (BAC) for such activity or WBS as illustrated in Equation (1).

$$\text{Planned Value (PV)} = \text{Planned Progress} \times \text{Budget At Completion (BAC)} \quad (1)$$

- Earned value: Earned value (EV) is an activity's or WBS component's value of work actually completed as indicated in terms of the approved budget given to that task. Equation (2) shows how this parameter can be obtained.

$$\text{Earned Value (EV)} = \text{Actual Progress} \times \text{Budget At Completion (BAC)} \quad (2)$$

Actual cost: Actual cost (AC) is the entire expense actually expended and reported for carrying out work for an activity or WBS component.

Once PV, EV, and AC have been determined, performance indices and cost/time variances can be calculated to describe the project's current (to date) and future (to complete and at completion) status .

Schedule Variance (SV), Cost Variance (CV), Schedule Performance Index (SPI) and Cost Performance Index (CPI) are variances and performance indices that describe the project's current (to date) status.

- Schedule Variance (SV): is an effective way for identifying possible schedule delays or possibilities for schedule acceleration. SV is calculated using the formula presented by Equation (3). A positive SV indicates the project is ahead of schedule, a negative SV indicates the project is behind schedule and an SV equaling 0 indicates the project is on schedule.

$$\text{Schedule Variance (SV)} = \text{EV} - \text{PV} \quad (3)$$

- Cost Variance (CV): is a form of variance analysis that measures project progress against the project's cost baseline. CV is calculated using the formula presented by Equation (4). A positive CV means the project is under budget, while a negative CV indicates it is over budget.

$$\text{Cost Variance (CV)} = EV - AC \quad (4)$$

- Schedule Performance Index (SPI): indicates the current project status whether it is ahead or behind the baseline schedule. SPI is calculated using the formula presented by Equation (5). An SPI value greater than or equal to 1 ( $\geq 100\%$ ) indicates the time allocated to the project has been used efficiently. An SPI value less than 1 ( $<100\%$ ) indicates the use of project time resources may need to be more efficient.

$$\text{Schedule Performance Index (SPI)} = \frac{EV}{PV} \quad (5)$$

- Cost Performance Index (CPI): indicates the current project status whether it is over budget or under budget based on the actual cost. Equation (6) is used to calculate CPI. A CPI value greater than 1 ( $> 100\%$ ) indicates the project is under budget. A CPI value less than 1 ( $<100\%$ ) indicates the project is over budget and it may need to be more efficient.

$$\text{Cost Performance Index (CPI)} = \frac{EV}{AC} \quad (6)$$

In addition to variances and performance indices related to current (to date) performance, EVM enables management team to develop a forecast for the estimates related to future (to complete and at completion) status. Estimate to Complete (ETC), Estimate at Completion (EAC), and Variance at Completion (VAC) are the most popular estimates that describe the project's future based on information and knowledge available at the time of the forecast.

- Estimate to Complete (ETC): reflects the estimated cost needed to finish the project's remaining work. According to [22], three approaches are utilized to calculate ETC: 1) considering that the remaining work is at the budgeted rate, 2) considering that the remaining work is at the present CPI, and 3) considering both SPI and CPI. These three approaches are presented by Equations (7), (8) and (9) respectively.

$$\text{Estimate To Complete (ETC)(1st approach)} = BAC - EV \quad (7)$$

$$\text{Estimate To Complete (ETC)(2nd approach)} = \frac{BAC - EV}{CPI} \quad (8)$$

$$\text{Estimate To Complete (ETC)(2nd approach)} = \frac{BAC - EV}{CPI} \quad (8)$$

- Estimate at Completion (EAC): EAC is typically based on the actual costs incurred for work completed plus an estimate to complete (ETC) the remaining work as illustrated by Equation (10).

$$\text{Estimate At Completion (EAC)} = AC + ETC \quad (10)$$

- Variance at Completion (VAC): VAC is a crucial metric in EVM because it enables project managers to estimate the project's ultimate cost performance and to decide how to alter budgets, reallocate resources, or take corrective action to restore original cost plan. VAC is calculated using the formula presented by Equation (11).

$$\text{Variance At Completion (VAC)} = \text{Budget At Completion (BAC)} - \text{Estimate At Completion (EAC)} \quad (11)$$

### 3.2. General Considerations for the Proposed Mathematical Approach

In this study, a mathematical approach is developed to address the effect of task's quality status on the variances and performance indices provided by EVM technology. In this context, the developed approach handles the additional cost resulting from defects/nonconformities associated with producing poor-quality items .

The proposed approach takes into account the following considerations:

- The total Actual Cost ( $AC_{p,q}$ ) is classified into two components: ( $AC_p$ ) and ( $AC_q$ ).  $AC_p$  is the actual cost incurred and recorded in accomplishing the physical work performed for an activity excluding any additional cost related to poor quality.  $AC_p$  is the actual cost incurred in accomplishing the work that the EV measured. On the other hand,  $AC_q$  represents the additional actual cost incurred due to quality issues. In other words,  $AC_q$  represents the poor-quality cost incurred for scrap, rework, repair, re-testing, failure analysis, etc.

- Just like  $AC_{p,q}$ , the total Estimate to Complete ( $ETC_{p,q}$ ) is classified into two components: ( $ETC_p$ ) and ( $ETC_q$ ).  $ETC_p$  is the estimated cost needed to finish the activity's remaining work excluding any estimates for additional cost related to poor quality. Consequently,  $ETC_q$  is the estimated cost needed to complete handling of poor quality consequences.

- Forecasting  $ETC_p$  and  $ETC_q$  is based on information and knowledge available at the time of the forecast. The proposed approach, however, gives users the option to define  $ETC_q$  as a user-defined estimate. This option is ideal when updating risk information which would lead to a user-defined estimate of a future poor-quality cost resulting from recently emerging quality risk, which the activity has not exposed to. This option allows users to define the unbudgeted good-quality cost.

- In this study, three quality patterns are defined for in-progress activities: full conformance, partial conformance and full non-conformance.

- Full conformance: it represents a quality pattern when no quality issues have occurred to date (i.e. the entire work performed to date is totally accepted). Accordingly, no cost related to poor quality was recorded. In this quality status,  $AC_q$  is equal to zero and  $ETC_q$  is, by default, equal to zero unless it is defined by the user, as previously illustrated, in case of recently emerging quality risk or unbudgeted good-quality cost.

- Partial conformance: it represents a quality pattern when some items of the work performed (at any time of the activity duration from the actual start to the data date) have not successfully completed. Accordingly, additional actual cost is incurred due to quality issues. In a quality status of partial conformance, the proposed approach provides three options for performance measuring and estimates forecasting. Each option reflects one of the following possible quality statuses at the date of evaluation and forecasting (i.e. the data date):

- 1) Handling poor-quality work has been successfully completed. The work performed (including the work required to rectify defects) has been accepted or about to be accepted, no extra cost associated with the quality issues -already occurred- is expected to last. In this case,  $ETC_q$  is, by default, equal to zero unless it is defined by the user in case of recently emerging quality risk or unbudgeted good-quality cost.

- 2) Handling poor-quality work is continuing and the remaining work is at the present CPI that combines the effect of  $AC_p$  and  $AC_q$ . In this case, as agreed by the user, the proposed model provides estimates for both  $ETC_p$  and  $ETC_q$  based on information and knowledge available at the time of the forecast.

- 3) Handling poor-quality work is continuing. Nevertheless, CPI is calculated based on the effect of  $AC_p$  only. Accordingly, the proposed model provides estimate only for  $ETC_p$ . In this case, as agreed by the user,  $ETC_q$  is defined by the user himself. This option is ideal if the cost of handling poor-quality work is not consistent over the duration of the activity.

- Full non-conformance: it represents a quality pattern when the entire work performed to date has been totally rejected. Accordingly, additional cost related to poor quality is inevitable. In this quality status,  $AC_p$  is equal to zero as no adequate work has been actually achieved (i.e. both actual progress and EV are equal to zero).  $ETC_p$  is then equal to BAC. On the other hand,  $AC_q$  is the actual cost incurred to perform the rejected work that represents waste/scrap cost. The user has to define  $ETC_q$  that is used a) to complete rectifying all the defects, b) in case of recently emerging quality risk or c) in case of unbudgeted good-quality cost.

### 3.3 Integrating the Proposed Mathematical Approach with Task's Quality Status

In this study, the general considerations proposed in the previous subsection are employed to develop a mathematical approach for implementing the EVM Calculator tool. In this subsection, the algorithm developed to expand the scope of EVM parameters –to reflect the effect of task's quality status- is presented for each of the three pre-defined quality patterns: full conformance, partial conformance and full non-conformance. It should be noted that, the following equations developed for each quality pattern must be read in conjunction with the general background on EVM and the considerations previously illustrated.

- General formulas:

PV and EV are calculated according to Equations (1) and (2) respectively. The total Actual Cost ( $AC_{p,q}$ ) is given by:

$$AC_{p,q} = AC_p + AC_q \quad (12)$$

The total Estimate to Complete ( $ETC_{p,q}$ ) is calculated using Equation (13).

$$ETC_{p,q} = ETC_p + ETC_q \quad (13)$$

The Estimate at Completion (EAC) is given by:

$$EAC = AC_{p,q} + ETC_{p,q} \quad (14)$$

Variance at Completion (VAC) is estimated according to Equation (11).

- Formulas for in-progress tasks of Full Conformance:

In this quality pattern, as described in the previous subsection,  $AC_q$  is equal to zero and  $ETC_q$  is, by default, equal to zero unless it is defined by the user. Accordingly,  $CPI$ ,  $ETC_p$ ,  $ETC_{p,q}$ , and EAC are given by Equations (15), (16), (17) and (18) respectively.

$$CPI = \frac{EV}{AC_p} \quad (15)$$

$$ETC_p = \frac{BAC - EV}{CPI} \quad (16)$$

$$ETC_{p,q} = ETC_p + ETC_q \text{ (if any/user-defined)} \quad (17)$$

$$EAC = AC_p + ETC_{p,q} \quad (18)$$

- Formulas for in-progress tasks of Partial Conformance:

This quality pattern, as explained earlier, includes three possible options as follows:

1) Handling poor-quality work has been successfully completed.

In this case,  $AC_{p,q}$  is computed using the general formula presented by Equation (12). On the other hand, as handling nonconformities has been completed,  $ETC_q$  is, by default, equal to zero unless it is defined by the user. Accordingly,  $CPI$ ,  $ETC_p$  and  $ETC_{p,q}$  are given by Equations (19), (20) and (21) respectively. EAC is, then, computed using Equation (14).

$$CPI = \frac{EV}{AC_p} \quad (19)$$

$$ETC_p = \frac{BAC - EV}{CPI} \quad (20)$$

$$ETC_{p,q} = ETC_p + ETC_q \text{ (if any/user-defined)} \quad (21)$$

2) Handling poor-quality work is continuing and CPI combines the effect of both  $AC_p$  and  $AC_q$

In this case,  $AC_{p,q}$  is computed using Equation (12). In addition, CPI and  $ETC_{p,q}$  are calculated according to the following Equations (22) and (23) respectively. Using the general formula presented by Equation (14), EAC is estimated.

$$CPI = \frac{EV}{AC_p + AC_q} \quad (22)$$

$$ETC_{p,q} = \frac{BAC - EV}{CPI} \quad (23)$$

This option assumes that the ETC work (to complete both types of work: rectifying defects and achieving the work planned) is continuing at the same CPI as that incurred by the project to date. In this option, estimate for  $ETC_q$  is implicitly calculated. In just this way, the user provides consent to accept a model-based estimate for  $ETC_q$  rather than a user-defined one.

3) Handling poor-quality work is continuing and CPI is only based on  $AC_p$

This option assumes the cost of rectifying defects/nonconformities is not consistent over the duration of the activity. Consequently, the user has to define  $ETC_q$ . In this case, CPI,  $ETC_p$  and  $ETC_{p,q}$  are given by Equations (24), (25) and (26) respectively.

$$CPI = \frac{EV}{AC_p} \quad (24)$$

$$ETC_p = \frac{BAC - EV}{CPI} \quad (25)$$

$$ETC_{p,q} = ETC_p + ETC_q \text{ (user-defined)} \quad (26)$$

$AC_{p,q}$  and EAC are calculated using the general formulas presented by Equations (12) and (14) respectively.

- Formulas for in-progress tasks of Full Non-conformance:

In this quality pattern, no actual progress is earned. Accordingly, both  $AC_p$  and EV are equal to zero.  $ETC_p$  is, therefore, equal to BAC and the user has to define  $ETC_q$ . It should be noted that,  $AC_q$  represents waste/scrap cost as pointed out earlier. Accordingly, estimates for  $ETC_p$ ,  $ETC_{p,q}$ , and EAC are given by Equations (27), (28) and (29) respectively.

$$ETC_p = BAC \quad (27)$$

$$ETC_{p,q} = BAC + ETC_q \text{ (user-defined)} \quad (28)$$

$$EAC = AC_p + ETC_{p,q} \quad (29)$$

In addition to the proposed formulas for cost forecasting, this study adopts a formula for forecasting the total remaining duration ( $RD_{p,q}$ ) of the project activities as follows:



$$RD_{p,q} = RD_p + RD_q \quad (30)$$

Equation (30) indicates that the total remaining duration ( $RD_{p,q}$ ) is categorized into two components: ( $RD_p$ ) and ( $RD_q$ ).  $RD_p$  represents the remaining duration required to complete the work planned excluding any additional time for tackling the nonconformities. Based on the original plan (i.e. the original duration), it is proposed that  $RD_p$  for a certain task is given by:

$$RD_p = \text{Original Duration}(OD) - \text{Actual Progress} \times \text{Original Duration}(OD) \quad (31)$$

On the other hand,  $RD_q$  is defined by the user. It reflects the extra quality-based time required a) to complete rectifying all the remaining defects, b) in case of recently emerging quality risk or c) in case of unplanned good-quality time.

#### 4. Testing and Validation of the Proposed Mathematical Approach

The proposed mathematical model presented in this paper is employed to implement EVM Calculator tool. This section describes the validation work carried out to evaluate EVM Calculator tool in terms of: 1) providing appropriate EVM parameters and estimates to ensure effective response suitable for any type of quality pattern and 2) achieving effective integration with Primavera P6 for scheduling purposes. A project consisting of 36 activities was utilized to test and validate the functionality of EVM Calculator tool. The original plan of this project is presented in Appendix Table (A1). This table includes, for each activity, data about activity name, original duration, immediate predecessors, relationship type, lag, planned start, planned finish and BAC.

Using Primavera P6, scheduling results for the project understudy show that the total project duration is 109 working days and based on 7-day workweek calendar, the project start and end dates are 01-Jan-2023 and 19-Apr-2023 respectively. On the other hand, the total project BAC is EGP 13,072,112.

Considering the planned/budgeted data (i.e. the project's baseline), four different simulation scenarios were developed to simulate the project's performance. Each scenario is associated with a certain data date (i.e. the date of evaluation and forecasting) and includes different combinations of quality patterns for in-progress activities. Data dates for the four test scenarios 1, 2, 3 and 4 were assumed to be 07-Jan-2023, 07-Jan-2023, 09-Jan-2023 and 21-Jan-2023 respectively. In association with these dates, project progress information assumed for the test scenarios 1, 2, 3 and 4 are presented in Appendix Tables (A2), (A3), (A4) and (A5) respectively. These tables include, for each finished and in-progress activity, the following data (in the order in which data appears in the table): 1) Activity name, 2) Original duration, 3) BAC, 4) Actual start date, 5) Actual finish date (for finished activities), 6) Quality pattern, 7) Actual progress, 8)  $AC_p$ , 9)  $AC_q$ , 10) Continual state of handling poor-quality work (yes or no), 11)  $ETC_q$  (model-based estimate or user-defined), and 12)  $RD_q$  (user-defined).

Each scenario of the four test scenarios was considered a separate and independent project progress status, which contains time/cost records available at the corresponding data date, to use for project evaluation. Beyond the developed model, Primavera P6 was used to conduct four independent evaluations associated with the four test scenarios. P6 was equipped to adopt Equation (8) for cost forecasting, while Equations (30) and (31) were used to calculate activity remaining duration for time forecasting. It should be noted that, because the project activities are associated with various quality patterns which requires employing multiple approaches for performance evaluation and forecasting, results provided by P6 should be revised and may be altered to conform to the activity's quality status.

Results of evaluation and time/cost forecasting for the four test scenarios 1, 2, 3 and 4 are presented in Tables (1), (2), (3) and (4) respectively. These tables provide evaluation results for finished, in-progress activities and the entire project. Evaluation results include 1) Budget at completion (BAC), 2) Earned value (EV), 3) Actual cost (AC), 4) Cost performance index (CPI), 5) Estimate to complete (ETC), 6) Estimate at completion (EAC), 7) Variance at completion (VAC), 8) Remaining duration (RD) and 9) Variance of finish date (VFD).

**Table (1): Results for test scenario (1) provided by Primavera P6 with altered results considering quality status**

Project/Activity	BAC (EGP)	EV (EGP)	AC (EGP)	CPI [altered]	ETC (EGP) [altered]	EAC (EGP) [altered]	VAC (EGP) [altered]	RD (days)	VFD (days)
The entire project	13,072,112	951,293	1,007,000	0.945	12,162,380 [12,145,379]	13,169,380 [13,152,379]	97,268 [-80,267]	109	-6
Piles 400 mm Diameter	796,312	796,312	810,000	0.98	0	810,000	-13,688	0	-2
Soil Excavation	99,968	84,973	94,000	0.904	16,588	110,588	-10,620	3	-4
Soil Replacement	350,042	70,008	80,000	0.875 [0.933]	320,002 [300,000]	400,002 [380,000]	-49,960 [-29,960]	2	-4
Piles Cap shuttering Works	31,460	0	23,000	0	31,460 [34,460]	54,460 [57,460]	23,000 [-26,000]	4	-6

**Table (2): Results for test scenario (2) provided by Primavera P6 with altered results considering quality status**

Project/Activity	BAC (EGP)	EV (EGP)	AC (EGP)	CPI [altered]	ETC (EGP) [altered]	EAC (EGP) [altered]	VAC (EGP) [altered]	RD (days)	VFD (days)
The entire project	13,072,112	951,293	1,004,000	0.948	12,162,380 [12,154,968]	13,166,380 [13,158,968]	-94,268 [-86,856]	112	-9
Piles 400 mm Diameter	79,6312	796,312	810,000	0.983	0	810,000	-13,688	0	-2
Soil Excavation	99,968	84,973	94,000	0.904 [0.988]	16,588 [16,176]	110,588 [110,176]	-10,620 [-10,208]	3	-4
Soil Replacement	350,042	70,008	80,000	0.875 [0.933]	320,002 [306,002]	400,002 [386,002]	-49,960 [-35,960]	5	-7
Piles Cap shuttering Works	31,460	0	20,000	0	31,460 [38,460]	51,460 [58,460]	-20,000 [-27,000]	4	-9

**Table (3): Results for test scenario (3) provided by Primavera P6 with altered results considering quality status**

Project/Activity	BAC (EGP)	EV (EGP)	AC (EGP)	CPI [altered]	ETC (EGP) [altered]	EAC (EGP) [altered]	VAC (EGP) [altered]	RD (days)	VFD (days)
The entire project	13,072,112	951,293	1,004,000	0.948	12,162,380 [12,154,968]	13,166,380 [13,158,968]	-94,268 [-86,856]	112	-9
Piles 400 mm Diameter	79,6312	796,312	810,000	0.983	0	810,000	-13,688	0	-2
Soil Excavation	99,968	84,973	94,000	0.904 [0.988]	16,588 [16,176]	110,588 [110,176]	-10,620 [-10,208]	3	-4
Soil Replacement	350,042	70,008	80,000	0.875 [0.933]	320,002 [306,002]	400,002 [386,002]	-49,960 [-35,960]	5	-7
Piles Cap shuttering Works	31,460	0	20,000	0	31,460 [38,460]	51,460 [58,460]	-20,000 [-27,000]	4	-9

**Table (4): Results for test scenario (4) provided by Primavera P6 with altered results considering quality status**

Project/Activity	BAC (EGP)	EV (EGP)	AC (EGP)	CPI [altered]	ETC (EGP) [altered]	EAC (EGP) [altered]	VAC (EGP) [altered]	RD (days)	VFD(days)
The entire project	13,072,112	2,100,503	2,090,900	1	10,981,718 [11,001,718]	13,072,618 [13,092,618]	-506 [-20,506]	101	-12
Piles 400 mm Diameter	796,312	796,312	715,000	1.11	0	715,000	81,312	0	-3
Soil Excavation	99,968	99,968	100,000	1	0	100,000	-32	0	-3
Soil Replacement	350,042	350,042	365,000	0.96	0	365,000	-14,958	0	-1
Piles Cap shuttering Works	31,460	31,460	33,000	0.95	0	33,000	-1540	0	-4
Piles Cap steel Works	639,760	639,760	700,000	0.91	0	700,000	-60,240	0	-4
Piles Cap pumping Works	188,760	169,884	160,000	1.06 [1.06]	17,778 [37,778]	177,778 [197,778]	10,982 [-9,018]	3	-11
Piles Cap deshuttering Works	880	880	900	0.98	0	900	-20	0	-3
Soil Filling	40,656	12,197	17,000	0.72	39,666	56,666	-16,010	5	-12

The findings shown in Tables (1), (2), (3) and (4) revealed that, there was no need to alter performance and forecasting results for a number of in-progress activities. This is because the performance and forecasting formulas required to express the proper quality pattern of such activities are fully matched with those provided by Primavera P6. Examples of these activities are "Soil Excavation", "Soil Replacement" and "Soil Filling" in test scenarios (1), (3) and (4) respectively. The best description for the quality pattern of these activities is "partial conformance, handling poor-quality work is continuing, CPI combines the effect of both  $AC_p$  and  $AC_q$  and a model-based estimate for  $ETC_q$  is accepted". Accordingly, the proper formulas to calculate  $CPI$  and  $ETC_{p,q}$  for such activities are those presented by Equations (22) and (23) respectively. As explained earlier, Equation (22) combines the effect of the total actual cost (i.e.  $AC_p$  and  $AC_q$ ) while, Equation (23) combines the effect of the total estimate to complete (i.e.  $ETC_p$  and  $ETC_q$ ), which are fully aligned with the formulas adopted via applying P6 (i.e. Equations (6) and (8) respectively). That is why; the results of such activities are not altered.

On the other hand, if calculation of  $CPI$  is only based on  $AC_p$  (when handling poor-quality work is not consistent over the duration of the activity), results should be revised and then altered to reflect the proper features of the corresponding quality pattern. The following are examples: 1) "Soil Replacement" in test scenario (1), 2) "Soil Excavation" in test scenario (2), 3) "Soil Replacement" in test scenario (2), 4) "Pile Caps Shuttering Works" in test scenario (3) and 5) "Pile Caps Pumping" in test scenario (4).

In addition, despite unmodified  $CPI$ , estimates for ETC, EAC and VAC are revised as the estimate  $ETC_q$  is defined by the user. This can be found for the activities belonging to a quality pattern characterized as "full conformance" or "full non-conformance". In the project understudy, examples are 1) "Pile Caps Shuttering works" in test scenario (1), 2) "Pile Caps Shuttering Works" in test scenario (2), 3) "Soil Excavation" in test scenario (3) and 4) "Pile Caps Steel Works" in test scenario (3).

For comparative purposes and to achieve the validation objectives, the developed EVM Calculator tool is applied to perform performance evaluation and forecasting for the same four test scenarios. Screenshots of reports on the results provided by EVM Calculator tool for the four test scenarios 1, 2, 3 and 4 are presented in Figures (3), (4), (5) and (6) respectively.

Project/Activity	BAC	EV	AC	CPI	ETC	EAC	VAC	RD	VFD
entire Project	13072112	951293.2	1007000	0.945	12145391.5	13152391.5	-80280.18	109	-6
Piles 400 mm Diameter	796312	796312	810000	0.9831	0	810000	-13688	0	-2
Site Excavation	99968	84972.8	94000	0.904	16587.61	110587.61	-10619.61	3	-4
Soil Replacement	350042	70008.4	80000	0.9334	300014.57	380014.57	-29972.57	2	-4
Shuttering Piles Cap	31460	0	23000	0	34460	57460	-26000	4	-6

Figure 3: A screenshot for a report on the results of the test scenario (1)

Project/Activity	BAC	EV	AC	CPI	ETC	EAC	VAC	RD	VFD
entire Project	13072112	951293.2	1004000	0.948	12154980.36	13158980.36	-86868.36	112	-9
Piles 400 mm Diameter	796312	796312	810000	0.9831	0	810000	-13688	0	-2
Site Excavation	99968	84972.8	94000	0.9881	16175.79	110175.79	-10207.79	3	-4
Soil Replacement	350042	70008.4	80000	0.9334	306014.57	386014.57	-35972.57	5	-7
Shuttering Piles Cap	31460	0	20000	0	38460	58460	-27000	4	-9

Figure 4: A screenshot for a report on the results of the test scenario (2)

Project/Activity	BAC	EV	AC	CPI	ETC	EAC	VAC	RD	VFD
entire Project	13072112	1002042.8	1064000	0.942	12007328.95	13071328.95	779.62	116	-15
Piles 400 mm Diameter	796312	796312	858000	0.9281	0	858000	-61688	0	-4
Site Excavation	99968	49984	30000	1.6661	33000.6	63000.6	36967.4	5	-8
Soil Replacement	350042	140016.8	104000	1.3463	156001.78	260001.78	90040.22	4	-10
Shuttering Piles Cap	31460	15730	12000	1.573	12000	24000	7460	4	-12
Steel works Piles Cap	639760	0	60000	0	651760	711760	-72000	4	-15

Figure 5: A screenshot for a report on the results of the test scenario (3)

Project/Activity	BAC	EV	AC	CPI	ETC	EAC	VAC	RD	VFD
entire Project	13072112	2100502.8	2090900	1.005	11001715.75	13092615.75	-20503.75	101	-12
Piles 400 mm Diameter	796312	796312	715000	1.1137	0	715000	81312	0	-3
Site Excavation	99968	99968	100000	0.9997	0	100000	-32	0	-3
Soil Replacement	350042	350042	365000	0.959	0	365000	-14958	0	-1
Shuttering Piles Cap	31460	31460	33000	0.9533	0	33000	-1540	0	-4
Steel works Piles Cap	639760	639760	700000	0.9139	0	700000	-60240	0	-4
Pumping Piles Cap	188760	169884	160000	1.0618	37777.36	197777.36	-9017.36	3	-11
De shuttering Piles Cap	880	880	900	0.9778	0	900	-20	0	-3
Soil Filling to SOG Work Level	40656	12196.8	17000	0.7175	39664.39	56664.39	-16008.39	5	-12

Figure 6: A Screenshot for a report on the results of the test scenario (4)

Comparing performance evaluation and forecasting results presented in Figures (3), (4), (5) and (6) with those presented in Tables (1), (2), (3) and (4) respectively, reveals the effectiveness of the developed EVM Calculator tool. Not only is EVM Calculator tool effective in providing appropriate EVM parameters and performing cost-based performance evaluation and forecasting, because it ensures also effective integration with Primavera P6 for scheduling and time-based performance evaluation and forecasting.

## CONCLUSION

The primary focus of several researchers to improve BIM-based models is related to time, cost and clash detection. Studies based on the integrated application of BIM and construction quality management combining the effect of quality issues on EVM variables are very rare. The main objective of this current study is to apply EVM technique in a BIM-based model in order to enhance monitoring of project's time and cost performance taking task's quality status into account. The main deliverable of this study is a developed BIM-based model including three plugins: Bill of Quantity (BOQ) estimator, Quality inspector, and EVM controller.

This paper focuses on providing details about the mathematical model developed to implement EVM Calculator tool. Implementing EVM Calculator tool required 1) developing an algorithm to expand the scope of EVM parameters and variances in order to address the effect of task's quality status on cost-based performance evaluation and forecasting and 2) establishing effective integration with Primavera P6 for scheduling purposes and to investigate the effect of task's quality on the schedule deviations. To this end, for in-progress activities, three major quality patterns are defined: full conformance, partial conformance and full non-conformance. According to the features defined for

each pattern, the corresponding EVM formulas are developed.

Based on planned/budgeted data for a project consisting of 36 activities, four separate and independent project progress statuses were used to test and validate the developed EVM Calculator tool. Beyond the developed model and fully relying on Primavera P6, results for project's time and cost performance evaluation and forecasting were obtained for each of the test scenarios. As P6 was equipped to adopt a single approach for evaluation and forecasting, it was necessary to revise and alter the produced results to conform to the characteristics of each activity's quality pattern. For comparative purposes, data of the same four test scenarios were used once more but this time via applying the developed EVM Calculator tool. Comparing the outcomes of the developed tool to the results provided by P6 demonstrated that the developed EVM Calculator tool ensures competency and effectiveness from both a cost and time perspective. The developed model provides appropriate EVM parameters and estimates ensuring effective response suitable for any type of quality pattern. Further, it ensures the achievement of effective integration with Primavera P6 to perform scheduling operations and updates.

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**Appendix**

**Table (A1): Original Plan of the Project Understudy**

Activity Name	Predecessor	Relationship	Lag (days)	Planned Start mm/dd/yyyy	Planned Finish mm/dd/yyyy	Duration (days)	Budget (EGP)
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Piles 400 mm Diameter	-----	-----	0	1/1/2023	1/1/2023	1	796,312
Site Excavation	Piles 400 mm Diameter	FS	0	1/2/2023	1/5/2023	4	99,968
Soil Replacement	Site Excavation	FS	0	1/6/2023	1/7/2023	2	350,042
Shuttering Piles Cap	Soil Replacement	FS	0	1/8/2023	1/9/2023	2	31,460
Steel works Piles Cap	Shuttering Piles Cap	FS	0	1/16/2023	1/16/2023	1	639,760
Pumping Piles Cap	Steel works Piles Cap	FS	0	1/17/2023	1/18/2023	2	188,760
De shuttering Piles Cap	Pumping Piles Cap	FS	2	1/21/2023	1/21/2023	1	880
Soil Filling to SOG Work Level	De shuttering Piles Cap	FS	0	1/22/2023	1/24/2023	3	40,656
SOG Floor – Shuttering	Soil Filling to SOG Work Level	FS	0	1/25/2023	1/25/2023	1	30,314
SOG Floor – Steel	SOG Floor - Shuttering	FF	1	1/25/2023	1/26/2023	2	1,741,520
SOG Floor - Pumping Concrete	SOG Floor - Shuttering	FS	0	1/27/2023	1/28/2023	2	698,280
	SOG Floor – Steel	FS	0				
SOG Floor - De Shuttering	SOG Floor - Pumping Concrete	FS	2	1/31/2023	1/31/2023	1	440
SOG Floor - Shuttering Coulmns&Walls	SOG Floor - De Shuttering	FS	0	2/1/2023	2/4/2023	4	18,700
	SOG Floor - Coulmns&Walls Steel	FF	1				
SOG Floor - Coulmns&Walls Steel	SOG Floor - De Shuttering	FS	0	2/1/2023	2/1/2023	1	176,880
SOG Floor - Pumping Coulmns&Walls Concrete	SOG Floor - Shuttering Coulmns&Walls	FS	0	2/5/2023	2/5/2023	1	54,120
	SOG Floor - Coulmns&Walls Steel	FS	0				
SOG Floor - De shuttering Coulmns&Walls	SOG Floor - Pumping Coulmns&Walls Concrete	FS	2	2/8/2023	2/11/2023	4	5,280
Gr Slab - Shuttering	SOG Floor - De shuttering Coulmns&Walls	FS	0	2/12/2023	2/15/2023	4	38,500
Gr Slab - Slab Steel	Gr Slab - Shuttering	FF	1	2/15/2023	2/16/2023	2	1,609,520
Gr Slab - Pumping Slab Concrete	Gr Slab - Shuttering	FS	0	2/17/2023	2/18/2023	2	642,840
	Gr Slab - Slab Steel	FS	0				
Gr Slab - De Shuttering Slab	Gr Slab - Pumping Slab Concrete	FS	7	2/26/2023	2/28/2023	3	3,960
Gr Slab - Shuttering Walls & Columns	Gr Slab - De Shuttering Slab	FS	0	3/1/2023	3/4/2023	4	18,700
	Gr Slab - Walls & Columns Steel	FF	1				

**Table (A1) (continued): Original Plan of the Project Understudy**

Gr Slab - Walls & Columns Steel	Gr Slab - De Shuttering Slab	FS	0	3/1/2023	3/1/2023	1	176,880
Gr Slab - Pumping Walls & Columns Concrete	Gr Slab - Shuttering Walls & Columns	FS	0	3/5/2023	3/5/2023	1	54,120

	Gr Slab - Walls & Columns Steel	FS	0				
Gr Slab - De shuttering Walls & Columns	Gr Slab - Pumping Walls & Columns Concrete	FS	2	3/8/2023	3/11/2023	4	5,280
1st Slab – Shuttering	Gr Slab - De shuttering Walls & Columns	FS	0	3/12/2023	3/15/2023	4	38,500
1st Slab – Steel	1st Slab - Shuttering	FF	1	3/15/2023	3/16/2023	2	1,609,520
1st Slab - Pumping Concrete	1st Slab - Shuttering	FS	0	3/17/2023	3/18/2023	2	642,840
	1st Slab - Steel	FS	0				
1st Slab - De Shuttering	1st Slab - Pumping Concrete	FS	7	3/26/2023	3/28/2023	3	3,960
1st Slab - Shuttering Walls & Columns	1st Slab - De Shuttering	FS	0	3/29/2023	4/1/2023	4	18,700
	1st Slab - Walls and Columns Steel	FF	1				
1st Slab - Walls and Columns Steel	1st Slab - De Shuttering	FS	0	3/29/2023	3/29/2023	1	5,280
1st Slab - Pump Columns	1st Slab - Shuttering Walls & Columns	FS	0	4/2/2023	4/2/2023	1	176,880
	1st Slab - Walls and Columns Steel	FS	0				
1st Slab - Deshuttering Walls & Columns	1st Slab - Pump Columns	FS	2	4/5/2023	4/8/2023	4	54,120
Roof - Shuttering Slab Floor	1st Slab - Deshuttering Walls & Columns	FS	0	4/9/2023	4/12/2023	4	58,300
Roof - Slab Steel Works	Roof - Shuttering Slab Floor	FF	1	4/12/2023	4/13/2023	2	1,899,040
Roof - Pumping Slab Floor	Roof - Shuttering Slab Floor	FS	0	4/14/2023	4/15/2023	2	1,137,840
	Roof - Slab Steel Works	FS	0				
Roof - De Shuttering Slab	Roof - Pumping Slab Floor	FS	7	4/23/2023	4/25/2023	3	3,960

**Table (A2): Progress Information for test scenario (1) (Data Date: 07-Jan-2023)**

Activity Name	Original Duration (OD)	Total Budget Cost (BAC)	Actual Start Date	Actual Finish Date	Quality Pattern (In-progress Activities)	% Complete (Actual Progress)	Actual Progress Cost (AC <sub>p</sub> )	Actual Quality Cost (AC <sub>q</sub> )	Continual State of Handling Poor-Quality work???	ETC <sub>q</sub>	RD <sub>q</sub>
Piles 400 mm Diameter	1	796,312	2-Jan-23	3-Jan-23	Finished	100	800,000	10,000	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Excavation	4	99,968	3-Jan-23	N.A (in-progress activity)	Partial Conformance	85	86,000	8,000	Yes	Model-based Estimate	2
Soil Replacement	2	350,042	5-Jan-23	N.A (in-progress activity)	Partial Conformance	20	75,000	5,000	No	0 (handling poor-quality finished)	0
Piles Cap shuttering Works	2	31,460	6-Jan-23	N.A (in-progress activity)	Full Non-conformance	0	0	23,000	Yes	3,000 (user-defined)	2

**Table (A3): Progress Information for test scenario (2) (Data Date: 07-Jan-2023)**

Activity Name	Original Duration (OD)	Total Budget Cost (BAC)	Actual Start Date	Actual Finish Date	Quality Pattern (In-progress Activities)	% Complete (Actual Progress)	Actual Progress Cost (AC <sub>p</sub> )	Actual Quality Cost (AC <sub>q</sub> )	Continual State of Handling Poor-Quality???	ETC <sub>q</sub>	RD <sub>q</sub>
Piles 400mm Diameter	1	796,312	2-Jan-23	3-Jan-23	Finished	100	800,000	10,000	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Excavation	4	99,968	3-Jan-23	N.A (in-progress activity)	Partial Conformance	85	86,000	8,000	Yes	1000 (user-defined)	2
Soil Replacement	2	350,042	5-Jan-23	N.A (in-progress activity)	Partial Conformance	20	75,000	5,000	No	6,000 (user-defined due to new quality risk)	3
Piles Cap shuttering Works	2	31,460	6-Jan-23	N.A (in-progress activity)	Full Non-conformance	0	0	20,000	No	7,000 (user-defined due to new quality risk)	2

**Table (A4): Progress Information for test scenario (3) (Data Date: 09-Jan-2023)**

Activity Name	Original Duration (OD)	Total Budget Cost (BAC)	Actual Start Date	Actual Finish Date	Quality Pattern (In-progress Activities)	% Complete (Actual Progress)	Actual Progress Cost (AC <sub>p</sub> )	Actual Quality Cost (AC <sub>q</sub> )	Continual State of Handling Poor-Quality???	ETC <sub>q</sub>	RD <sub>q</sub>
Piles 400 mm Diameter	1	796,312	2-Jan-23	5-Jan-23	Finished	100	850,000	8,000	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Excavation	4	99,968	6-Jan-23	N.A (in-progress activity)	Full Conformance	50	30,000	0	N.A (full conformance pattern)	3,000 (user-defined due to new quality risk)	3
Soil Replacement	2	350,042	7-Jan-23	N.A (in-progress activity)	Partial Conformance	40	100,000	4,000	Yes	Model-based Estimate	2
Piles Cap shuttering Works	2	31,460	8-Jan-23	N.A (in-progress activity)	Partial Conformance	50	10,000	2,000	No	2,000 (user-defined due to new quality risk)	3
Piles Cap steel Works	1	639,760	8-Jan-23	N.A (in-progress activity)	Full Non-conformance	0	0	60,000	Yes	12,000 (user-defined)	3



**Table (A5): Progress Information for test scenario (4) (Data Date: 21-Jan-2023)**

Activity Name	Original Duration (OD)	Total Budget Cost (BAC)	Actual Start Date	Actual Finish Date	Quality Pattern (In-progress Activities)	% Complete (Actual Progress)	Actual Progress Cost ( $AC_p$ )	Actual Quality Cost ( $AC_q$ )	Continual State of Handling Poor-Quality???	$ETC_q$	$RD_q$
Piles 400 mm Diameter	1	796,312	2-Jan-23	4-Jan-23	Finished	100	700,000	15,000	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Excavation	4	99,968	4-Jan-23	8-Jan-23	Finished	100	100,000	0	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Replacement	2	350,042	7-Jan-23	8-Jan-23	Finished	100	360,000	5,000	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Piles Cap shuttering Works	2	31,460	10-Jan-23	13-Jan-23	Finished	100	33,000	0	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Piles Cap steel Works	1	639,760	13-Jan-23	14-Jan-23	Finished	100	700,000	0	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Piles Cap pumping Works	2	188,760	15-Jan-23	N.A (in-progress activity)	Partial Conformance	90	160,000	0	Yes	20,000 (user-defined)	2
Piles Cap deshuttering Works	1	880	18-Jan-23	18-Jan-23	Finished	100	900	0	N.A (finished activity)	0 (finished activity)	0 (finished activity)
Soil Filling	3	40,656	19-Jan-23	N.A (in-progress activity)	Partial Conformance	30	13,000	4,000	Yes	Model-based Estimate	2

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