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(Research Paper)

Project Control Based on the Earned Volume of Consumables

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Abstract

Purpose: A project can be controlled based on three approaches: 1) cost, 2) time duration, and 3) volume of consumables. Several methods such as earned value management (EVM), earned duration management (EDM), and earned schedule (ES) have been proposed by researchers to control a project. These methods are capable of controlling a project based on cost and duration terms, however, in real practice one needs to analyze the progress of a project considering material volumes consumed for activities or work packages. This paper aims to propose a novel method for controlling a project based on the volume of consumables of the project.

Design/methodology/approach: In practice, the cost analysis of a project is affected directly by the consumable volumes of the project. In other words, the real project progress is more sensitive to material volumes than time duration and cost factors. The approach of the proposed method allows project management to pool different consumable volume units of different activities and work packages leading to control them separately and jointly.

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Findings: Monitoring earned volumes of consumables of a construction project helps practitioners effectively interpret and analyze the real progress of a project. Controlling the material of a project leads effectively project engineers to evaluate: 1) the real status of the project progress, 2) waste material, and 3) reworks. This approach leads managers to provide an effective method to predict the duration and cost of a project more realistically.

Practical implications: In this research, different terms are proposed to analyze the progress of a project in practical cases effectively. In this paper to investigate the capability of the proposed method, a real project case is studied.

Originality/value: The existing models in the literature are not capable of analyzing the status of the real material volumes consumed in practice. In this proposed method, to analyze the progress of a project, it is allowed to pool the different units of volumes without a unit of measure. This feature of the proposed method allows engineers to use the proposed method for all project types.

Keywords: Earned bulk management (EBM), earned value management (EVM), Earned duration management (EDM), Earned schedule (ED), project control

1. Introduction

Earned value management (EVM) as an efficient method has played an important role in new approaches to integrated project control. In the last two decades, different indicators have been proposed based on EVM, to evaluate the performance of a project. Most of these indicators are based on cost and time dimensions. This approach attempts to perform the progress analysis by comparing the planned data and actual implementation records leading to keeping the project on track. EVM focuses on analyzing the performance of the project management based on cost and financial terms ([Kim et al., 2003](#)), ([Liu et al., 2022](#)), and ([Aramali et al., 2023](#)). Lipke ([2003](#)) showed that there is an important problem when one uses the EVM method. The EVM uses two important terms to analyze the progress of a project: 1) schedule performance index (SPI) and 2) schedule variance (SV). When one uses EVM, at the completion of all projects, SPI and SV are equal unity and zero, respectively, even if the project is terminated with a time delay. The SV indicator addresses whether the project has been performed on schedule or not. A negative value of SV indicates that the project is behind schedule whereas the positive value of SV shows that the project is ahead of the schedule. In the case that SV is equal to zero value, one interprets that the project has progressed exactly as scheduled. SV indicator is calculated as the following equation.

$$SV = EV - PV \quad (1)$$

Where EV and PV denote the cumulative earned and planned values at a determined time, respectively. The SPI index is calculated based on equation 2.

$$SPI = \frac{EV}{PV} \quad (2)$$

The SPI indicator is a measure of how close the project is to being completed compared to the schedule. If this index addresses a value higher than 1, it indicates that the project is progressing well against the schedule at a specified time. In the case that the SPI is equal to 1, then one concludes that the project is progressing exactly as planned. In the condition that the project is running behind schedule, the SPI is less than 1 value. Consider a project which is behind its schedule, in this case, one expects that the indicators show the falling behind the project schedule over the time of the project. Lipke ([2003](#)) described that when a project manager uses EVM, at the completion of the case that a project has been running behind schedule, SV and SPI equal zero and 1 values, respectively. It means that the project has progressed exactly as scheduled, however the project manager knows that the project has been completed late. The analysis showed that SPI and SV are not two accurate and reliable measures for analyzing a project's performance. Lipke ([2003](#)) also described that the EVM approach measures the performance of a project in cost units, not units of time and then proposed a new method based on the concept of earned schedule named (ES) method. Later Khamooshi and Golafshani ([2014](#)) proposed an earned duration management (EDM) method to control the progress of a project compared to its schedule. Khamooshi and Golafshani ([2014](#)) decoupled schedule and cost performance measures and proposed indexes leading to analyze the progress of a project. Literature review indicates that EVM, ES, and EDM are the three main methods approached in the last decade in the literature.

Based on the three approaches, several different authors have contributed to developing different methods to analyze and control the progress of a project. Noori et al. ([2008](#)) used a fuzzy control chart for earned value analysis. Pajares et al. ([2011](#)) proposed two metrics that combine EVM and Project risk management for project controlling and monitoring. Colin & Vanhoucke ([2014](#)) based on the EVM method proposed a new statistical project control to provide setting tolerance limits leading to improving the discriminative power between progress situations. The method proposed by Colin & Vanhoucke ([2014](#)) used the statistical method to analyze situations compared with the project baseline schedule. Yousefi & Currie ([2016](#)) and Yousefi et al ([2019](#)) applied statistical control charts on EDM indices. They claimed that the statistical method is capable of analyzing the variations in project schedule performance. Sackey et al. ([2020](#)) developed a model to improve the estimate at completion (EAC) term in the EVM method. They claimed that the proposed forecasting helps project management to schedule metrics accurately. Andrade & Vahoucke ([2017](#)) proposed a method based on combining EDM and EVM methods. The proposed method follows a simplification approach for project time and cost management. Leu et al. ([2006](#)) attempted to improve the performance of traditional EVM using statistical control chart methods. They claimed that the proposed method allows analysis of in-progress project cost and schedule trends. They discussed that the proposed approach is capable of highlighting possible needs for corrective

action. Leu et al. (2006) explained that their proposed statistical control technique can assist practitioners in managing project performance effectively. Sogandi et al. (2015) also approached the statistical process control to monitor the indexes of the EVM method for analyzing the performance of a project. Batselir & Vanhoucke (2016) focused on improving project forecast accuracy using the integration of earned value management (EVM) with exponential smoothing and reference class forecasting. Ballesterose et al. (2019) proposed two new EVM metrics for monitoring and controlling projects. In this paper, they proposed Earned Schedule min (ES_{min}) and Earned Schedule max (ES_{max}) terms. Bagherpour et al. (2020) to enhance the performance of conventional EVM, categorized the factors on EVM into four main clusters and then the most effective ones are separated from the clusters. Priyo (2021) analyzed four units of building construction projects using the EVM method consisting of 1) a project performance analysis, 2) cost estimation, and 3) time for project completion, along with a planning estimation analysis against project completion. Almeida et al. (2021) analyzed the impact of uncertainty in the progress measurement in earned value analysis. Mahmoudi et al. (2021) approached earned duration management under uncertain conditions. Sheikhalishahi et al. (2022) attempted to improve earned value management (EVM) and earned schedule (ES) using statistical quality control charts considering the existence of dependence between cost and schedule. Liu et al. (2022) used earned value management for greenhouse gas emissions management in prefabrication and modular. Acebes et al (2022) approached stochastic methods to analyze earned duration for project schedule management. Bakhshandeh & Zare Mehrjerd (2022) estimated project efficiency based on a dynamic simulation model of earned value management. They claimed that the proposed approach can be used to determine the impact of various project management functions on improving project efficiency. Aramali et al. (2023) introduced a framework to measure EVMS maturity, including 56 attributes arrayed across ten subprocesses. These attributes together make up an integrated project/program management system. They examined the relationship between the proposed maturity model and ten project performance metrics through statistical analyses. Table 1 addresses the reference approaches controlling a project based on the earned concept.

As described above, the literature indicates that consumable volumes of activities of a project have not been contributed by the proposed methods of the literature approached earned concept. The proposed methods of the literature used the earned concept for the duration of time and cost, while the consumable volume plays the most important role in the project scheduling and its real progress report.

Table 1. References of the literature approached EVM, ES, and EDM

NO.	Reference	Approach type			
		Earned value	Earned schedule	Earned duration	Combination
1	Lipke (1999)	✓			
2	Noori et al. (2008)	✓			
3	Pajares & Lopez (2011)	✓			
4	Colin & Vanhoucke (2014)	✓			
5	Lipke (2003)		✓		
6	Khamooshi & Golafshani (2014)			✓	
7	Yousefi & Currie (2016)			✓	
8	Yousefi et al. (2019)			✓	
9	Sackey et al. (2020)	✓			
10	Andrede & Vahoucke (2017)				✓
11	Leu et al. (2006)	✓			
12	Sogandi et al. (2015)	✓			
13	Batselir & Vanhoucke (2016)	✓			
14	Khamooshi & Abdi (2017)			✓	
15	Ballesterose et al. (2019)		✓		
16	Bagherpour et al. (2020)	✓			
17	Priyo (2021)	✓			
18	Almeida et al. (2021)	✓			
19	Mahmoudi et al. (2021)			✓	
20	Sheikhalishahi et al. (2022)	✓			
21	Liu et al. (2022)	✓			
22	Acebes et al. (2022)			✓	
23	Bakhshandeh & Zare Mehrjerd (2022)	✓			
24	Aramali et al. (2023)	✓			

Really the progress of a project occurs when consumable volumes corresponding to the project improve. The consumable volume term has wide application in project management and is usually used by contractors, clients and project offices to analyze the real progress of a project. How to progress the consumable volume of activities is one of the most important concerns of contractors and employer project managers. This paper proposes a new method to analyze the performance of a project based on consumables corresponding to the deliverable activities of a project. The novel proposed method of this paper provides a good understanding of the real progress of a project for all levels of project managers. Furthermore, the analysis of the real progress trend of a project based on consumable units (especially when a project is terminated) provides invaluable information for project managers and engineers.

The remainder of this paper is organized as follows: The next section is allocated to describe the opportunity provided by the proposed method of this paper. The third section introduces completely the proposed method for controlling a project. The fourth section considers the use of the proposed method in a real project case. Finally, concluding remarks are provided in Section 5.

2. Opportunities provided by monitoring consumables

The project cost estimate is directly related to the consumables corresponding to products or work packages. Materials which are consumed in a project can be categorized into two groups: 1) Renewable materials (such as human and machine resources), and 2) Non-renewable materials (such as construction materials, concrete and rebar). Methods which are used to construct a project affect the type of materials and consequently their volumes. Furthermore, tender documents of a project are prepared based on the methods and volume of consumables designed for the project.

Assume a contractor wants to participate in a tender. After the contractor receives the tender documentation, an engineering team starts to analyze the methods and volume of material designed for the project. This analysis leads the team to estimate the cost of constructing the project leading to a bid price. If the volumes and methods change during the construction process of the project, its cost will be affected and changed. In some cases, the project design is revised and naturally, the volume sizes will be changed. However, in very real cases, without revising the design, the volume of consumables increases due to reworks, material waste, variation of technical specification of materials, and inefficient planning. In a project, controlling the volume of consumables plays an important role in the success of project management. Now assume that the project is controlled using EVM or EDM by the contractor. In this case, all the related terms of EVM or EDM are monitored. In these methods, although the management is led to analyze the cost or schedule time of the project, it is not possible to conclude: 1) How much has the project progressed based on the volume of consumables?, 2) How much of the time delays are related to changes in volume of consumables?, 3) How much of the increased cost is related to changing of the volume size consumables?, and 4) Does the increased cost affect provisional statement or the final statement (the statement should be completed based on the volumes recorded in the contract and tender documentations)?

When a project is monitored based on the volume of consumables of products and work packages, it is possible to control and analyze reworks and resource wastes of the project. Once a project is controlled based on the cost, and the actual cost overruns are compared to planned costs, EVM is unable to identify the cause(s) of reworks or wastes or both of them.

Project managers are interested usually in knowing the progress of the project based on the volume size of consumables over time of the implementation of the project. Controlling a project focusing on volumes of products not only helps engineers to control the schedule time and cost simultaneously but also provides the condition of analyzing methods, machines, men, and materials as well as the environment of constructing work packages or products. Controlling a project based on the volume of consumables leads to improving the contractor's know-how during the implementation of the project.

3. Proposed Earned Bulk management (EBM)

Project controlling is the process of observing the project plan implementation, collecting data on implementation, performing analysis by comparing the planned data with the actual implementation data, and finally keeping the project on track using data analysis. As discussed in the introduction, the earned approach is one of the most widely accepted approaches by practitioners in the project management field. In this research, we use the data collected in the process of monitoring and controlling project management to develop controlling measures. The necessary data is obtained based on the quantity surveying and contractor statement. As this required data is used by project management teams, there will be no additional costs for data collection to produce reports for the proposed method of this paper.

As described in the previous section, the existence of project control methods leads practitioners to analyze the performance of a project based on cost or schedule duration measures. However, the volume of consumables of activities and work packages is capable of addressing the more realistic condition of the project performance. Really, in practice, the actual progress of a project can be well addressed by volume units. In this paper, we present a critical evaluation of earned bulk assessing schedule performance. Then a comprehensive set of new indices is introduced which are easy to measure and status understanding in real managing projects. These indices can be used to measure the real bulk progress and performance of the project in application. As an example, the bulk performance index (BPI) measures the bulk-based progress of the project compared to the used actual bulk. We also discuss the potential advantages of these measures. Additionally, we develop estimation performance measures which can be used effectively by contractors, clients, and the scheduling offices to assess the estimated and planned progress of a project. Though BPI(t) is argued to be a preferred option to measure performance compared to SPI. SPI has some conceptual shortcomings and could not be validated as a general method which is applicable to all scenarios. Consequently, EVM, ES, and EDM inherently are deficient in dealing with the measurement of consumed volume (i.e., real progress).

The aim of the proposed earned bulk of this paper is to provide a new method to monitor and analyze the performance of a project effectively based on the volume of consumables. Since in practice, the volume measurement units are different, the most important problem in analyzing the progress of a project in volume dimension is how to pool different volume units. In this research to pool different volume units corresponding to different activities, it is provided that the volumes without units are included in the calculation of the progress value.

The following steps should be provided by engineers before using EBM proposed in this paper:

- 1) Define all activities, products and work packages considering the work breakdown structure (WBS) of the project. A WBS is a structured description of the work that will be performed to execute a project. WBS provides a hierarchy of tasks to demonstrate a good understanding of the work and task composition for the project team.
- 2) Define precisely all units of consumables of the project.
- 3) Calculate the volume of consumables related to all deliverable products/activities.
- 4) Prepare the schedule and cost of activities as well as define the relationship between the project activities.

In this proposed method, at any point in time to analyze the progress of a project, it is allowed to pool the different units of volumes without a unit of measure. For this aim, we propose focusing on the percentage of progress instead of the unit of any type of volume. For example, consider three different measures for three different deliverable product types, say a ton, cubic meter, and square meter for a project. Obviously, it is not possible to sum the volume values of these materials leading to a report on the progress percentage of the project. To overcome the problem, it is proposed that firstly one calculates the progress percentage of each material. In this way, the calculated percentages do not have a measurement unit and then different volumes of materials can be pooled. In this case, the following calculation is performed:

$$\frac{\text{Actual bulk}}{\text{Planned bulk}} \times 100 = \% \text{ bulk progress} \quad (3)$$

The result of equation 3 indicates that no unit of measurement governs it. Hence in this proposed approach, it is possible to pool different bulks with different units in percent term. Monitoring the progress of a project based on cost and time cannot address a clear and realistic picture of the actual status of the progress of the project in volume terms. The method approached in this paper leads practitioners to control and monitor a project effectively based on the quantity surveying and contractor statement.

For the proposed EBM three terms are defined: 1) planned bulk (PB), 2) earned bulk (EB), and 3) actual bulk (AB). These three terms lead practitioners to conclude the status of the existing progress of a project and predict the future volumes of the project. The following equation (4) leads to the calculation of PB for time t of the project progress analysis. In this equation, PB_t denotes the cumulative sum of planned bulks at time t of the project.

$$PB_t = \frac{\sum_{k=1}^v \left(\frac{\sum_{j=1}^t \sum_{i=1}^n PB_{ij}}{BAC_k} \times 100 \right)}{v_j} \quad k=1,2, \dots, v \text{ and} \quad (4)$$

$$v_j = \begin{cases} \frac{\sum_{j=1}^t \sum_{i=1}^n PB_{ij}}{BAC_k} \neq 0, & v_j = v \\ \frac{\sum_{j=1}^t \sum_{i=1}^n PB_{ij}}{BAC_k} = 0, & v_j = v - \text{the number of zeros} \end{cases}$$

Where PB_{ij} is the non-cumulative planned bulk of activity i in time period j . The summation on i is used for activities with the same unit of measurement. In this equation n denotes the number of activities since the start of the project up to and including time period t which are measured by the same unit. The count k indicates the measurement unit of bulk types used in the project, such as meter, cube meter, ton etc. In other words, since the bulk of each deliverable product is measured by a unique unit, the progress percentage of each product/activity should be separately calculated. Equation 4 indicates that there are v measurement unit types in a project. The abbreviation of BAC_k indicates the bulk at completion (BAC) for the bulk type k of the project. The description leads one to conclude that PB_t is the average planned progress at time t of v various volume types related to the project deliverable products.

The earned bulk and the actual bulk of a project at time t are calculated using Equations 5, and 6, respectively.

$$EB_t = \frac{\sum_{k=1}^v \left(\frac{\sum_{j=1}^t \sum_{i=1}^n EB_{ij}}{BAC_k} \times 100 \right)}{v} \quad k=1,2, \dots, v \quad (5)$$

$$v_j = \begin{cases} \frac{\sum_{j=1}^t \sum_{i=1}^n EB_{ij}}{BAC_k} \neq 0, & v_j = v \\ \frac{\sum_{j=1}^t \sum_{i=1}^n EB_{ij}}{BAC_k} = 0, & v_j = v - \text{the number of zeros} \end{cases}$$

$$AB_t = \frac{\sum_{k=1}^v \left(\frac{\sum_{j=1}^t \sum_{i=1}^n AB_{ij}}{BAC_k} \times 100 \right)}{v} \quad k=1,2, \dots, v \quad (6)$$

$$v_j = \begin{cases} \frac{\sum_{j=1}^t \sum_{i=1}^n AB_{ij}}{BAC_k} \neq 0, & v_j = v \\ \frac{\sum_{j=1}^t \sum_{i=1}^n AB_{ij}}{BAC_k} = 0, & v_j = v - \text{the number of zeros} \end{cases}$$

Figure 1 shows the concept of EB, PB, and AB during the time graphically. As shown in Figure 1, if one draws a line at a specified point in time parallel the horizontal axis from the EB curve until it intersects the PB curve, and then the intersection point is moved down, the obtained point indicates the time when the earned volume should have been obtained. The following equation 7 indicates this concept:

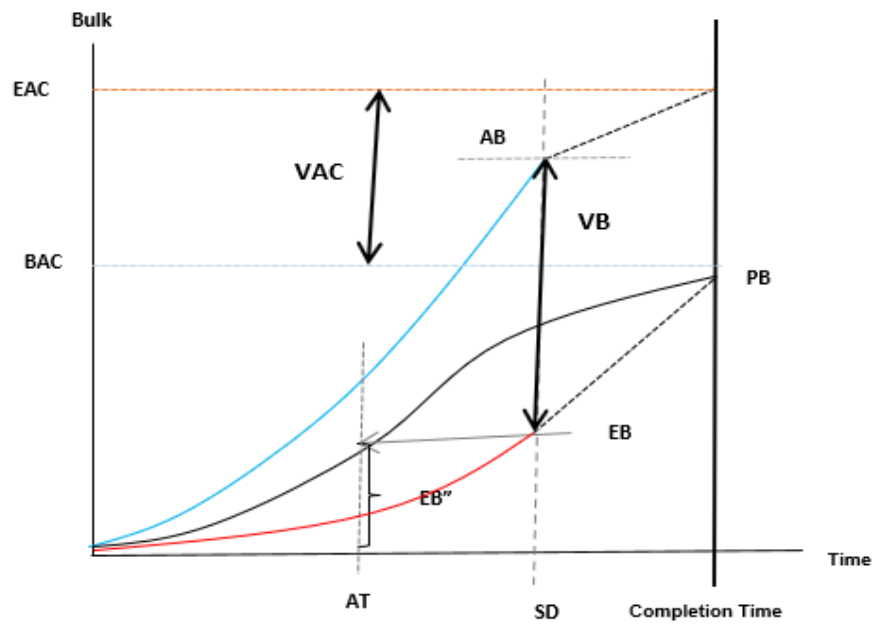
$$PB = EB_{AT} \quad (7)$$

where AT addresses the time of the above description. Figure 1 shows two possible cases in a project. Case 1 indicates the PB curve is below the AB curve and case 2 shows the PB curve is above the AB curve. In Figure 1, EAC indicates the estimate of completion of the project in bulk terms. Equation 8 indicates the bulk variance (BV) at time t .

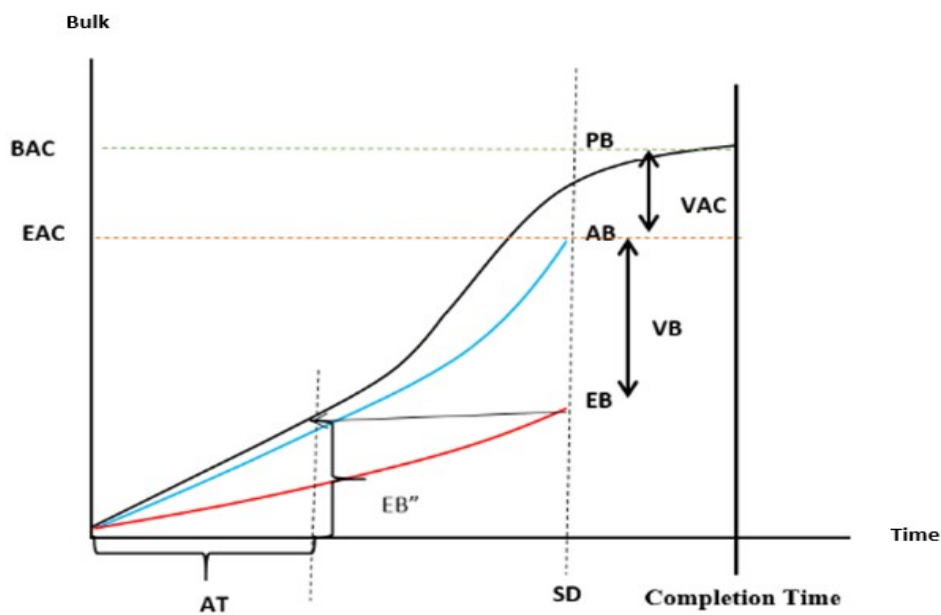
$$BV_t = EB_t - AB_t \quad (8)$$

where BV_t is the bulk variance of the project at time t and addresses the difference amount of the actual and the earned in volume term at time t . Table 2 shows different cases for the BV term and the corresponding interpretation of the project performance. The bulk performance index at time t (BPI_t) is also calculated by the following equation 9.

$$BPI_t = \frac{EB_t}{AB_t} \quad (9)$$



(Case 1)



(Case 2)

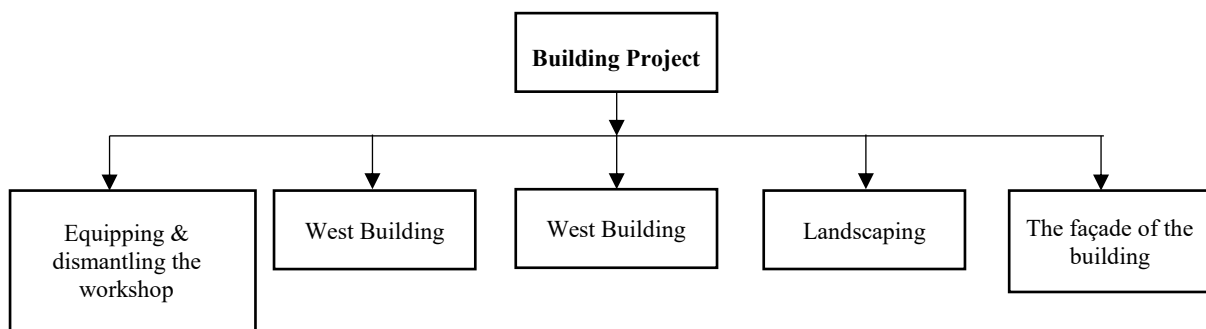
Fig. 1. Concept of Earned bulk indexes graphically

Table 2. BV cases may be provided in a project

Criteria	Project Status
$BV < 0$, $BPI < 1$	Volume is Behind schedule
$BV = 0$, $BPI = 1$	Volume is in accordance with the schedule
$BV > 0$, $BPI > 1$	Volume is ahead of schedule

4. Investigation of a real case study

In this section to demonstrate the performance of the proposed volume-based project control method, real project case data is investigated. The real case data correspond to a residential commercial building project in Tehran, Iran. The first level of the work breakdown structure (WBS) of the project is shown in Figure 2.

**Fig. 2. The first level of WBS of the case study**

The project was scheduled considering more than 2290 activities based on WBS. The schedule of the project predicts that the project will be terminated 593 days after the project is started. Table 3 indicates the progress reports of the project for 20 months using the EVM method. As shown in the CV and SV columns, all the values corresponding to the two indicators are negative. These mean that the project is behind schedule throughout its execution. As shown in the last record of Table 3, at the completion of the project SPI and SV are equal unity and zero, respectively. It means that the project progressed exactly as scheduled, however, we know that the project has been completed late.

Since reporting the measurement units of all activities of the project is not possible in this paper, as a part of the project activities, some activities (defined in the 3rd level of WBS of the third floor of the west building project) are shown in Table 4. In Table 4 all 16 general activities do not follow the same measurement unit. Table 4 intends to address that there are different measurement units for analyzing the project progress based on volume values in this project. Table 5 indicates the results corresponding to EBM indexes for each period considering the measurement unit of each activity.

Table 3. EVM report of the residential commercial building project

NO.	Report date	CV	CPI	SV	SPI	EAC
1	21/06/2019	-37,576,811	0.999	-37,499,062	0.999	579,892,354,046
2	22/07/2019	-82,668,983	0.998	-82,497,937	0.998	580,037,736,543
3	22/08/2019	-129,261,445	0.998	-128,993,992	0.998	580,246,887,155
4	22/09/2019	-175,865,417	0.998	-175,501,556	0.998	580,327,831,210
5	22/10/2019	-220,946,881	0.998	-220,489,722	0.998	580,229,468,554
6	21/11/2019	-266,035,470	0.998	-265,485,013	0.998	580,089,796,316
7	21/12/2019	-311,127,642	0.998	-310,483,888	0.998	580,026,085,628
8	20/01/2020	-356,223,808	0.998	-355,486,756	0.998	579,938,039,157
9	19/02/2020	-401,309,205	0.999	-400,478,855	0.999	579,897,416,939
10	19/03/2020	-444,895,522	0.999	-443,974,985	0.999	579,837,716,209
11	19/04/2020	-491,494,130	0.999	-490,477,185	0.999	579,869,197,975
12	20/05/2020	-538,090,005	0.998	-536,976,653	0.998	579,914,366,508
13	20/06/2020	-1,244,531,833	0.997	-1,243,322,073	0.997	580,968,296,346
14	21/07/2020	-2,494,393,078	0.994	-2,493,086,910	0.994	582,684,697,204
15	21/08/2020	-3,744,243,553	0.991	-3,742,840,978	0.991	584,160,812,948
16	21/09/2020	-4,995,078,611	0.989	-4,993,579,628	0.989	585,488,414,869
17	21/10/2020	-8,771,512,803	0.984	-4,868,928,209	0.991	588,519,967,411
18	20/11/2020	-14,746,436,034	0.975	-3,552,582,438	0.994	593,866,008,877
19	3/12/2020	-55,863,373,129	0.912	-75,926,078	1	634,899,217,685
20	19/01/2021	-75,250,576,142	0.885	0	1	654,279,094,498

Table 4. Measurement units of some activities for the case study

No.	Activity	Measurement unit	Volume	No.	Activity	Measurement unit	Volume
1	Preparation & implementation of fireproof insulation	m^2	750	9	Lighting cable piping	m	822
2	Wall post installation	kg	1671	10	Piping fire alarm system	m	232
3	Wall putting	m^2	264	11	Piping cable phone, antenna & iPhone	m	704
4	VERMIX implementation	m^2	110	12	Cable piping of electrical outlets	m	959
5	Installation of metal frame & subframe of doors and windows	kg	4500	13	Installation of keys & outlets	<i>number</i>	71
6	Implementation of floor concrete	m^2	70	14	Cabling fire alarm	m	231
7	Implementation of plastering	m^2	602	15	Lighting wiring	m	8713
8	Implementation of waterproofing	m^2	224	16	Cabling telephone & iPhone	m	440

Table 5. EBM report of the residential commercial building project

Report date	AT	(Duration) ($EB_{AT} = PB$)	PB%	EB%	AB%	BV_t	BPI	$EAC_B\%$
21/06/2019	32	34.285	1.787	2.062	2.262	-0.200	0.911	109.717
22/07/2019	62	66.527	4.958	5.615	5.816	-0.200	0.966	103.568
22/08/2019	93	96.558	7.790	8.263	8.425	-0.162	0.981	101.966
22/09/2019	124	127.521	12.403	13.106	13.398	-0.293	0.978	102.232
22/10/2019	154	158.084	18.596	19.256	19.443	-0.187	0.990	100.973
21/11/2019	184	188.466	27.015	28.514	28.572	-0.057	0.998	100.200
21/12/2019	214	218.351	33.456	33.818	33.886	-0.067	0.998	100.199
20/01/2020	244	248.632	35.391	35.978	36.045	-0.067	0.998	100.187

Report date	AT	(Duration) ($EB_{AT} = PB$)	PB%	EB%	AB%	BV_t	BPI	EAC _B %
19/02/2020	274	277.082	39.732	40.526	40.611	-0.085	0.998	100.211
19/03/2020	303	307.646	46.991	47.680	47.815	-0.135	0.997	100.282
19/04/2020	334	338.578	49.565	49.887	50.021	-0.134	0.997	100.269
20/05/2020	365	364.000	50.537	50.535	50.674	-0.139	0.997	100.275
20/06/2020	396	399.000	50.688	50.719	50.859	-0.140	0.997	100.276
21/07/2020	427	431.189	52.432	52.660	52.800	-0.140	0.997	100.265
21/08/2020	458	456.098	55.437	55.959	56.103	-0.144	0.997	100.257
21/09/2020	489	494.112	56.993	57.901	58.070	-0.169	0.997	100.291
21/10/2020	519	523.646	69.342	75.256	75.625	-0.368	0.995	100.490
20/11/2020	549	540.521	96.509	93.050	93.367	-0.316	0.997	100.340
03/12/2020	593	551.491	100.00	97.390	97.760	-0.370	0.996	100.380
19/01/2021	609	593.000	100.00	100.000	100.374	-0.374	0.986	100.374

Table 4 provides information to analyze the performance of the residential commercial building project based on volume size. Two EB and AB indexes help directly an engineer to analyze the progress and consumption of materials in this project.

5. Discussion

As mentioned above, for the novel proposed EBM method three terms: 1) planned bulk (PB), 2) earned bulk (EB), and 3) actual bulk (AB) were defined. These terms lead engineers to conclude the real status of the current progress of a project and predict the future volumes that will be consumed. However, the existing models in the literature are not capable of analyzing the status of the real material volumes consumed in practice. In this proposed method, to analyze the progress of a project, it is allowed to pool the different units of volumes without a unit of measure. This feature of the proposed method allows engineers to use the proposed method for all project types.

In the previous section, to demonstrate the performance of the proposed volume-based project control method, real project case data was investigated. The real case data correspond to a residential commercial building project in Tehran, Iran. Table 3 intends to address that there are different measurement units for analyzing the project progress based on volume values in this project. Table 4 indicates the results corresponding to EBM indexes for each period considering the measurement unit of each activity.

As shown in the EB and AB columns, all the calculated values in these columns follow the unequal $EB < AB$. It means that during the implementation of the project, the materials have been consumed more than the volumes calculated by the designer of the building. Since during the implementation of the project the quantity survey and estimation of material volumes have not been changed, the extra consumed material is related to reworks and waste materials. The analysis of the EBM method is capable of addressing the material consumed in excess of the project design amount, accurately. The column of BPI also addresses the ratio of the earned volume to the actual consumed volume. The values of this term indicate that the volumes consumed in this project are not the same amount calculated by the designer. Table

4 indicates that from 21-10-2020 date onwards the value of EB is less than PB. It means that the project from this date onwards is behind the base schedule. Table 4 also indicates that on the 03/12/2020 date based on PB value, at the end of the 593th day after the starting, the project should be terminated, however, EB value addresses that the earned volume of the project is 97.390 %. Figure 3 shows the S-curves of EB, PB, and AB of the studied project. This figure also shows the latest EAC and the bulk at completion (BAC) comparatively.

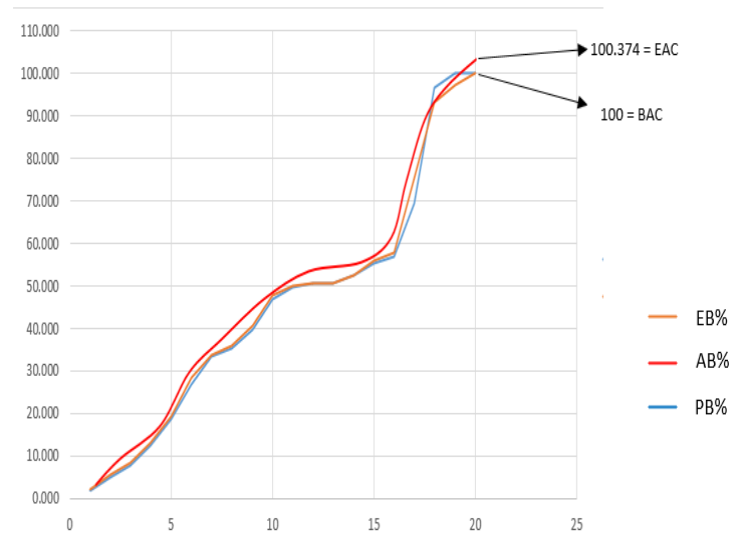


Fig. 3. PB, EB, and AB curves of the case study

EAC is calculated using the following equation 10 and BAC is calculated by the design engineer.

$$EAC_B = AB + \left(\frac{BAC - EB}{BPI} \right) \quad (10)$$

The mean absolute percentage error (MAPE) method forms the basis for expressing the real forecasting accuracy of a certain forecasting technique. The MAPE used by Vandevorode and Vanhoucke (2007), Rujiranyong (2009), and Vanhoucke (2010). The lower the MAPE for a particular forecasting method, the higher the accuracy of that method. MAPE is calculated as Equation 11:

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{A - F_t}{A} \right| \quad (11)$$

Where A is the actual final value and F_t denotes the forecasted value at time t. MAPE method for evaluating the proposed method is used in this research based on the following equation (12).

$$MAPE(\text{bulk}) = \frac{1}{n} \sum_{t=1}^n \frac{|RB - FBt|}{RB} \times 100 \quad (12)$$

The calculation indicates that MAPE is 0.71 for the proposed EBM however this index is obtained at 10.09 for the EVM method. The MAPE term addresses the high accuracy of the proposed model for monitoring a project based on analyzing material volume values for the project.

6. Conclusions

Literature addresses different methods based on cost and time terms that have been proposed by researchers for controlling the progress of a project. However, the methods introduced in the literature are not capable of providing a report considering the volumes of consumables for the project. The analysis of the progress of a project considering the volume of materials consumed for activities, is an essential report for project management. This paper proposed a method to monitor the progress of a project based on the volume of materials of activities with different measurement units. In this proposed method, data is obtained from quantity surveying and contractor statements as two important and reliable documents of the project. This research revealed that monitoring earned volumes helps practitioners effectively access the real progress of a project. This paper showed that controlling the material of a project leads effectively project engineers to the real status of the project progress, waste material, and reworks. This approach also leads project managers to predict the duration and cost of a project more realistically. The analysis of a real project case in this paper based on the EBM indexes found that the proposed approach of this paper provides a clear and real progress report for the project based on the volume of consumables. The analysis of MAPE addressed the high accuracy of the proposed EBM method. This research indicated that the EBM method is capable of providing an accurate picture of project progress in each time period during the construction of the project. Combined approaches including statistical methods are proposed for future research.

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Appendix

Notation	Description
AB	Actual bulk
AB_t	Actual bulk of a project at time t
BAC	bulk at completion
BAC_k	Bulk at completion for the bulk type k of the project
BPI	Bulk performance index
BPI_t	Bulk performance index at time t
BV	Bulk variance
BV_t	Bulk variance (BV) at time t
EAC	Estimate at completion of the project in bulk term
EB	Earned bulk
EB_t	Earned bulk of a project at time t
EBM	Earned bulk management
EDM	Earned duration management
EV	Earned value
EVM	Earned value management
ES	Earned schedule
MAPE	Mean absolute percentage error
PV	Planned value
SPI	schedule performance index
SV	Schedule variance
PB	Planned bulk
PB_t	the cumulative sum of planned bulks at the time t of the project
PB_{ij}	Non-cumulative planned bulk of activity i in time period j

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