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The role of time and cost control in CPM, PERT, and EVA methods in construction projects: A meta-analysis study onevaluating project performance

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ABSTRACT

Time and cost efficiency without reducing quality is something that construction service providers always want to achieve in the implementation of project completion. Project work will be limited by cost and time in completion. Methods of controlling time and costs can assist the Project Manager in evaluating project performance and taking actions needed to achieve project objectives. This study is about the comparison of research articles that have been published previously using Meta-Analysis Review which aims to compare three methods that are often used in controlling time and cost, namely CPM (Critical Path Method), PERT Method (Project Evaluation Review Technique), and EVA Method (Earned Value Analysis). The results obtained from the review of this article that each method of controlling costs and time has advantages and disadvantages following their respective characteristics, with that we can know differences of each method. The study found that experience from the Project Manager is needed to choose the right method for implementing project work.

1. Introduction

This article is a review of research and studies that discuss methods for controlling time and costs on construction projects. Time and cost efficiency are something that construction service providers always want to achieve without having to reduce the quality of the project. Some methods that are often used to control time and costs are the Critical Path Method (CPM) method, the Project Evaluation Review Technique (PERT) Method, and the Earned Value Analysis (EVA) Method. Some research that has been done previously is to manage the time and cost of a project activity using two methods from three methods. This article review attempts to discuss all three methods at once.

Two main reasons for the delay in the execution of project work are (1) unexpected events such as procedure failure, delays in the delivery of materials and structures, bad weather, natural disasters, accidents, and everything that is emergency and (2) slow implementation of the work itself [1]. Cost, quality, and time in implementing construction projects are the main limited resources, so planning, scheduling, and control are things that must be done so that the purpose of implementing projects with limited resources is achieved. Planning an effective schedule and cost-efficient planning without reducing quality is a challenge in project implementation [2]. Whatever the cause of delays in the work of a project needed control to anticipate it, especially in terms of cost and time. Cost and time

management is a part of project management that is always considered by construction service providers and users of construction services because it will provide its benefits for each party.

In a construction project work, delays are common, so that it impacts all project activities so that the right methods are needed to control parameters so that they can be efficient. Some studies also discuss ways to make the right decision for a problem [3], [4]. To control parameters to work efficiently and be able to pinpoint project conditions, integrated cost control, and schedule analysis system is needed [5]. One function of controlling costs and time in project management is how to reduce the deviations that occur in construction project work to minimize the risk of delays.

There is no the same project work, so each project has its uniqueness both in terms of work and construction. Environmental factors will also provide its uniqueness in project work. With the uniqueness of every construction project work, the right method in controlling cost and time is needed. Some methods in controlling time and cost are the CPM, PERT Method, and EVA Method. The objective of this study is to compare the right method for each construction work so that it can help and facilitate the project manager for mapping problems in project work. Besides, this research is expected to provide an overview of the advantages and disadvantages of each method in a construction project activity.

1.1. CPM (Critical Path Method)

The critical path is the path with the activity components with the longest total amount of time and shows the fastest time to complete a project. For the implementer of this critical path, the project becomes important because there are activities whose implementation must be on time because if there is a delay it will cause an overall delay. In the critical path method, there are two processes namely forward and backward calculations [6][7][8]. This method is often used in many management levels [9].Knowing the completion time based on experience or schedule data that has been made by the company can be used to compare the completion time of a project with the CPM. The CPM can also be used to determine the critical path in project planning and scheduling [10], [11]. The implementation of CPM is not difficult and has been recognized by developed countries [12]. This method also has a deficiency in scheduling resource usage [13], [14], [15].

Research using the CPM was carried out by Apri Widiya Laksana et al. The research optimizes the time and cost of the Randu Gunting River Cliff Protector project in Pati Regency and the work ofBodri River III in Kendal Regency (Central Java in Indonesia) which was then followed by crash program analysis through additional work hours. From this study, it was found that the most optimal project scheduling time on the Randu Gunting River Cliff Protector project was 147 days with a cost of IDR. 436,591,926.14 and the most optimal project scheduling in the Bodri River III project was 156days with a cost of IDR. 2,630 .378,619,24 [16].

The CPM is a project management technique that identifies activities on a critical path step by step. This method approaches the project schedule by dividing the project into several work tasks, displaying it in a flowchart, and calculating the duration of the project based on the estimated duration for each work. This method defines a very important job, saving time, in completing a project [17]. CPM is a method implementation for a certain project which determines finish time based on experience or schedule time data by creating a critical path using forward pass and backward pass calculation that can show activities that have to be punctual.

1.2. PERT (Project Evaluation Review Technique)

The PERT method has not emphasized the matter of minimizing costs but rather maximizing the time of project implementation. In the PERT method, the completion of certain jobs in the project is probabilistic, due to lack of experience. Random individual time activities will cause random project time. Likewise, what happens at the time of the activity and the critical path, if the time of random activities will cause a random critical path so that the critical path of project completion will become uncertain. This can be illustrated from the PERT method, which is the risk of uncertainty [18], [19], [20].

A comparison of the CPM and PERT methods was carried out by Dino Caesaron and Andrey Thio to conduct a time scheduling analysis on the Shop House development project in the Glodok area (a district in Jakarta Indonesia). Research using these two methods results in the same project completion time of 198 days where the PERT method has a probability of completion of 61 percent [21].

Implementation of the CPM and PERT methods can not only be done in building construction but can be done on a shipbuilding project in one of the shipbuilding companies as conducted by Abdurrasyid et al. The results obtained from the two methods are then followed up by making an application that can assist the project manager in monitoring every project activity implementation [10]. PERT can be used on some construction project or industry that has no experience in the process so that it has an uncertain critical path.

CPM and PERT assumed that the project has access to unlimited resources. The fact is, resources are extremely limited. Scheduling a project without considering resources can cause unreliable schedules and delays in the project as a result of resources and technology that are not available [22].

1.3. EVA (Earned Value Analysis)

There are 3 basic elements of the concept of EVA, namely the completion of work which is an illustration of the planned absorption of costs (budgeted cost), the actual cost used to complete the work, as well as the earned value which is the value obtained from the expenditure. This method is oneof the tools used to integrate costs and time in a project [23]. Earned Value is calculated based on the percentage of the weight multiplied by the contract value or the result of work completed from thetotal project budget [24].

One of the biggest advantages of Earned Value Management (EVM) is that it is relatively simple because it only requires information about a large percentage of project completion activities and actual costs, where the information is collected for various other purposes during the project implementation stage [25]. Some researchers discussed some specific weaknesses and limitations of the EVM framework, with the aim of better estimating the actual time of the project and/or taking better proactive or corrective actions during project implementation. [25]. EVA is a method that combines the time and cost of a project to inform project performance by using budgeted cost, actual cost, and earned value.

Paulo Andre de Andrade et al conducted a study aimed at improving the forecasting accuracy of a project by expanding the EVM concept of project regularity to EDM (Earned Duration Management). Based on empirical experiments conducted shows that the accuracy of the estimated duration of the project can be improved by focusing on schedule performance and schedule compliance [26]. EVA method can also be integrated with the CPM such as research conducted by Yunita Alfiana Messah et al, which examines the time and cost control related to the impact of design changes on the Oenaem Irrigation Embankment construction project where the results are initially estimated 7-week time-lapse can be reduced to 5 weeks and is estimated to save 0.326% of the total project expenditure [27].

The EVA method can also be compared to the PERT method to analyze performance. Aries Susanty et al conducted a study of the Banyumanik II Hospital development project in Semarang City, Central Java Indonesia, that project used the EVA method to assess performance and the PERT method for rescheduling the implementation of the project work. The results of the EVA method show that the performance index is less than 1, which means the work is experiencing delays. The PERT method provides several options regarding rescheduling the project [28]. EVA method can not only be used in building construction but can be done on JLS concrete retaining buildings in East Java Province which stretch from the West side of Pacitan and the East side of Banyuwangi (both cities are in East Java) which was studied by Edy Gardjito in 2017. The researcher can think that if the performance of the project implementation continues the same, it will experience a delay of 6 days even though the project can still provide a profit of IDR. 0.1924 billion [24].

EVM can also be used to measure sustainable performance in a project, as reviewed by Benjamin Koke and Robert C. Moehler by using a systematic review. The purpose of this review article is to find out whether EVM can be adapted to measure sustainable performance in projects. The results of this review article indicate that EVM has not been used to measure sustainability performance in projects so far. The author makes a conceptual framework for "Earned Green Value Management" so that EVM can be applied to the measurement of sustainability and project performance. This conceptual framework provides a theoretical foundation for tracking the achievement of sustainable goals in the project [29].

2. Method

2.1. CPM (Critical Path Method)

CPM is a method of determining the critical path using an arrow diagram so it is also called the critical path method. CPM implementation steps are shown in Fig. 1. Critical Path can show the fastest time component and the longest time component in project completion. The critical path is a path where activities are located which will result in overall project delays if an implementation is slow, and sometimes there is more than one critical path in one network [16] , [30]

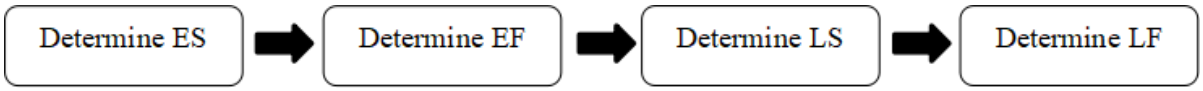

Fig. 1. CPM Implementation Steps

Calculation of the critical path in the CPM includes two stages, namely forward pass and backward pass. The forward pass starts from the "initial" node and moves to the "end" node, while the backward pass starts the calculation from the "end" node to the "initial" node. Table. 1 shows some terms in forwarding pass and backward pass.

Table 1. Terms in Forward Pass and Backward Pass

ES (earliest activity start time)	When starting a job.
EF (earliest activity finish time)	The earliest time the activity can be completed if it starts at the earliest time and is completed according to its duration. EF previous activities =
ES (earliest activity start time)	When starting a job.
	ES next activities.
LS (latest activity start time)	The last time the activity can be completed.
LF (Latest activity finish time)	The last time an activity can begin.
T (activity duration time)	The period required for an activity.
S (activity slack)	Grace period for starting or completing a job.

Source: D. Caesaron and A. Thio [21]

The rules in the forward pass are (1) Except for the first activity, the initial activity starts if the previous activity has been completed (2) EF is equal to ES plus the duration of the previous activity

(3) if the previous activity has two joining activities then ES = EF the biggest of the previous activities. The rules in the backward pass are (1) LS = LF minus the duration of the activity (2) if there is an activity split into two or more parts, then LF = LS is the smallest of the next activity. Slack time values can be calculated after counting forward passes and backward passes. In calculating using the CPM, there are 3 basic assumptions, namely (1) the project has only one initial event (start) and one terminal event (finish) (2) when the fastest occurrence of the initial event (start) is day zero and (3) The slowest occurrence of the terminal event (finish) is LS = ES [18].

This CPM is suitable for project activities that have been done before, so that the evaluator knows in advance about related time, data, and costs of each element of the activity. The focus emphasized onthis method is the accuracy of the project cost plan with realization. The type of information on working time on the CPM is the most right and appropriate time to complete a project, while the arrow on the CPM is to show project activities [10].

In the CPM, the project duration will not be longer than the longest path in the network. So that the total time elapsed for project completion is the same as the length of the critical path, the longest path in the network. Activities that are on that path are called critical activities. Late critical activities

will slow down overall project completion time. Therefore the project must be managed well to avoid delays in critical activities [17].

2.2. PERT (Project Evaluation Review Technique)

PERT method is a method of project evaluation by reducing as much as possible delays, conflicts, and disruptions in a project activity as well as coordinating and synchronizing to accelerate project completion [10]. PERT method is a method that has a degree of uncertainty throughout activities related to project implementation so that the existence of an element of probability is something that cannot be avoided from this method. The PERT method is a method for determining the magnitude of project completion opportunities according to the target time. The assumption that the period of an activity depends on many factors and variance is the approach used by the PERT method, so that the PERT method uses 3 estimated figures for each activity, namely (1) a = optimistic duration time (2) b = pessimistic duration time and (3) m = most likely time [31], . The three types of project completion time are used to determine the expected time (et). Also, in PERT to determine the uncertainty of a project, S (standard deviation) and V (et) variance are determined. PERT implementation steps are shown in Fig. 2.

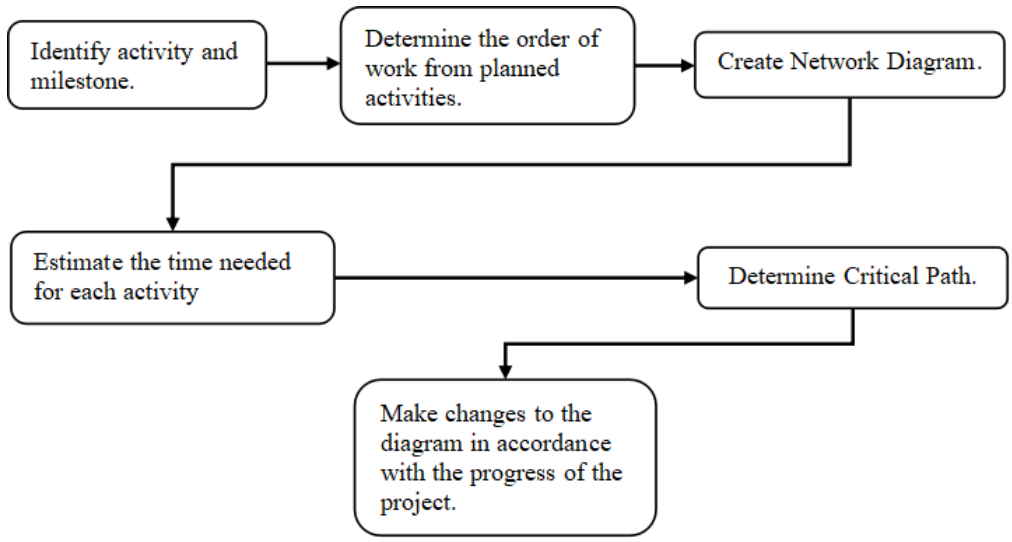

Fig. 2. PERT Implementation Steps (Source: Author's analysis of reviews of several related PERT articles [10], [18], [21], [28] , [31])

The focus of the PERT method is scheduling a project which is done by coordinating and synchronizing all elements of the project and completing the project as quickly as possible [28]. For planning and controlling projects that have never been done before, the PERT method is the most appropriate. According to the PERT Method, the timeliness factor is the main focus, because cutting time will have an impact on reducing project costs. In the PERT method, the arrows mention the sort order [10].

One of the advantages of the PERT method is that it not only recognizes the deviation in completion of each work during project time control but also assesses "where we are". Required condition is where the actual time of work is known, and calculates the deadline for the project, of course, by considering the work completed. In general, time control is based on a comparison of the planned and actual duration of work [1].

2.3. EVA (Earned Value Analysis)

One method for controlling project costs and schedules in an integrated manner is the EVA Method. This method provides cost and time prediction information for completion of all work required based on performance indicators and provides information on project performance status in a reporting period [32], [33]. EV shows how efficient a team project using project resources [34]. EVA implementation steps are shown in Fig. 3. This information can be used by a project manager to anticipate if deviations occur.

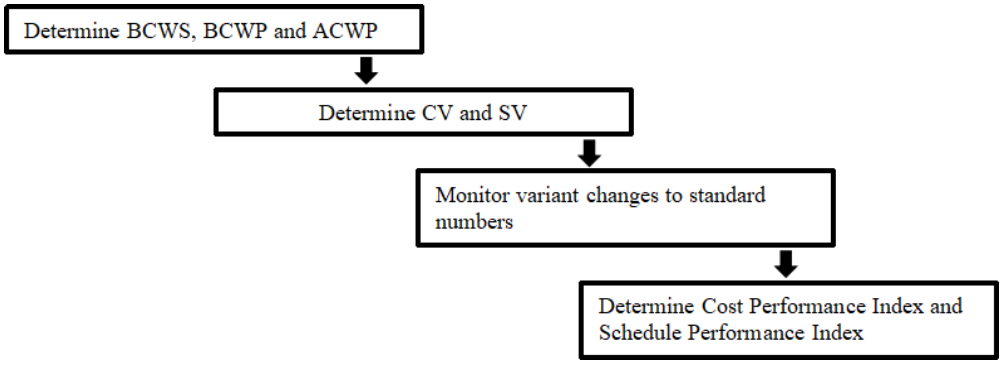

Fig. 3.EVA Implementation Steps (Source: Author's analysis of reviews of several EVA related articles [2], [5], [24] ,[28])

The concept of EV can show the amount of construction work that has been completed in addition to the actual and planned costs. This is what distinguishes the EVA method from conventional cost management methods that only show the relationship between actual costs and plan costs so that the real progress of some projects cannot be known. The fact is, changes in some project is inevitable. TheEVA method can provide a report to the project manager whether the costs incurred are proportionalto the performance generated [35].

EV method has 3 basic elements in analyzing the performance of the project as shown in Table. 2, namely (1) PV or Budgeted Cost for Work Scheduled (BCWS) is the cost budget for the work plan against the time that has been prepared (2) AC or Actual Cost for Work Performed (ACWP) is the costneeded to complete work within a certain time (3) EV or Budgeted Cost for Work Performed (BCWP) calculated from the number of completed works is the value received from the jobs completed for a certain amount of time [5], [23], [36]. PV, AC, and EV will remind the project manager to conduct preventive action to correct project performance [37]. The relationship between PV (BCWS), AC (ACWP), and EV (BCWP) show Cost Variance (CV) and Schedule Variance (SV) is shown in Fig. 4.

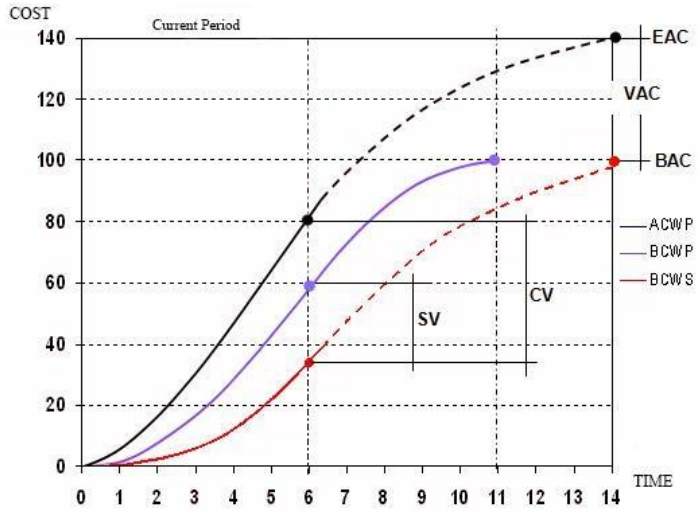

Fig. 4. Earned Value S Curve Graph (Source: [23], [38])

PV, EV, and AC are the basic metrics used by EVM to produce variances and performance index for financial performance and schedules before the work is done at a certain time, PV will make predictions of EV and AC. Then EV and AC will be measured after the work is done at a certain point in time. The EV and AC values are then used by the project manager to evaluate the status of project performance [39].

BCWS, ACWP, and BCWP indicators are used to calculate variants, both CV and SV, are shown in table 2. BCWS, ACWP, and BCWP indicators were also used to calculate the Cost Performance Index (CPI) obtained from BCWP/ACWP and Schedule Performance Index (SPI) obtained from

BCWP/BCWS. Further review of the performance index is shown in Table. 3. Usually, EVA only focused on CPI and SPI and is not discussing the satisfaction, healthiness, and safeness of the project owner. [38], [40], [41].

Table 2. Cost Variance and Time-Variant Analysis

No	Cost Variance (CV = BCWP - ACWP)	Explanation	Scheduled Variance (SV = BCWP - BCWS)	Explanation
1	Negative (-)	Cost Overrun	Negative (-)	Schedule Overrun
2	Zero (0)	The work was carried out according to plan	Zero (0)	Schedule according to plan
3	Positive (+)	Cost Underrun	Positive (+)	Schedule Underrun

Source: G. Y. M. H. Tarore and D. R. O. Walangitan [5]

Table 3. Conditions of Project Progress in Certain Periods.

Performance Index <1	Expenditure or implementation time is greater or longer than the planned budget and schedule
Performance Index > 1	Expenses or implementation time is smaller or faster than the planned budget and schedule
High-Performance Index (the greater the difference from the number 1)	Deviations that occur in the basic planning or large budget. Unrealistic planning is possible.

Source: G. Y. M. H. Tarore and D. R. O. Walangitan [5]

3. Results and Discussion

Based on the description above, there are similarities between the CPM, PERT, and EVA methods, namely (1) These three methods can be used by project managers to control time and costs on the construction project and (2) These three methods can be integrated with the methods used to remind the project completion time, for example, the crashing program or fast track unlike the crash program that reduces work time on the critical path with the most economical cost, fast track is project implementation method that implemented in parallel to fasten project. The difference between CPM, PERT, and EVA methods can be seen in Table. 4:

Table 4. Differences in CPM, PERT, and EVA Methods

No	Difference	CPM	PERT	EVA
1	Goal	Determine the project period based on the critical path. If activitiesin the critical path are delayed then the projectcompletion time will also be delayed.	Accelerate project implementation by reducing obstacles and disruptions that cause project delaysand coordinating and synchronizingall sections.	Analyze performance by integrating costs and timeand estimating the achievement of project objectives.
2	Basic idea	The main consideration is the event (event-oriented)	The arrow shows activity or job with activity information (activity-oriented)	Project status on a report (monitoring baseline)
3	Method Focus	The focus is on the accuracy of the project cost of the plan and realization. The CPM includes the concept of cost in planning and controlling.	Emphasized focus is time accuracy.This method focuses on scheduling a project by synchronizing and coordinating all parts of the project and try as fast as possible in completing the project. Costs in the PERT method are assumed to vary according to the length of time of all project activities.	Emphasized focus is the amount of physical work that has been completed over certain time. So the focus of the Earned Value Analysis method is controlling a project.
4	Project Type	Usually applied to projects that have been done before so that the time, data, and costs of each activity can be known in advance.	Usually applied to projects that have never been done before and do not have definite completion data. This method is used in projects where the estimated time of activities cannot be ascertained as	Can be done on all types of projects because this method emphasizes the amount of physical work that has been done and do not base on time.

No	Difference	CPM	PERT	EVA
		This method is used if the estimated working time of each activity can be well known, where the deviation is relatively small or can be ignored. This network-based method is not suitable for projects that have a repetitive nature (production level of repetitive activities) so it is not suitable for use in many unit projects.	having a very large time variation. This method is suitable for high-risk projects and large projects because this method is directed at the most accurate time and is designed to deal with situations with a high degree of uncertainty.	
5	Result	The project completion time and the relationship with available resources can be known with certainty	Project Scheduling and Budget have been determined before being implemented so that project work is more controlled and organized	Knowing CV whether experiencing Cost Overrun, costs according to plan or Cost Underrun Variants; Know the SV whether Schedule Overrun, schedule according to plan or Schedule Underrun.

Source: Authors' analysis from reviews of several articles related to CPM, PERT, and EVA

The three approaches are methods for evaluating the performance of a project through cost and time, so that project managers can get from the beginning if there are deviations that occur and can take appropriate policies to overcome them. PERT is a suitable method to be used on projects that have never been done and has high uncertainty and time variation. This is in contrast to CPM which is suitable for deterministic projects. EVA is the most suitable method for measuring project performance because it can determine the progress of a project activity so that performance results are more visible.

4. Conclusion

This review finds out that various methods of controlling costs and time in the project have some differences so that it requires experience from the project manager to be able to determine the right method for the current project. CPM is appropriate for projects that have been worked on so that the completion time and available resources can be known with certainty. PERT allows determining the time as soon as possible for the completion of a project that does not have definite completion data. EVA allows project managers to identify overall project performance. Each method has a different emphasis on processing existing data, but the project manager can evaluate the results of each report to take the necessary actions for anticipating if there are deviations that occur in project implementation. However, based on comparative studies there are advantages to EVA methods that are easier, faster, and supported by many tools (project management software) in evaluating project implementation.

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The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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References

[1] A. Mishakova, A. Vakhrushkina, V. Murgul, and T. Sazonova, "Project Control Based on a Mutual Application of Pert and Earned Value Management Methods," *Procedia Eng.*, vol. 165, pp. 1812–1817, Jan. 2016, doi: 10.1016/J.PROENG.2016.11.927.

[2] A. Ridwan and R. Ajiono, "Pengendalian Biaya Dan Jadual Terpadu Pada Proyek Konstruksi," *UKaRsT*, vol. 1, no. 1, p. 80, 2018, doi: 10.30737/ukarst.v1i1.84.

[3] E. Sonalitha, B. Nurdewanto, S. Ratih, N. R. Sari, A. B. Setiawan, and P. Tutuko, "Comparative Analysis of Tsukamoto and Mamdani Fuzzy Inference System on Market Matching to Determine the Number of Exports for MSMEs," *2018 Electr. Power, Electron. Commun. Control. Informatics Semin. EECCIS 2018*, pp. 440–445, Jul. 2018, doi: 10.1109/EECCIS.2018.8692989.

[4] M. Yu, X. Ding, H. Sun, K. Yu, and D. Zhao, "Role of fuzzy fractional differential equation in the construction of low carbon economy statistical evaluation system," *Alexandria Eng. J.*, vol. 59, no. 4, pp. 2765–2775, Aug. 2020, doi: 10.1016/J.AEJ.2020.05.031.

[5] J. (Junaidi) Junaidi, H. (Huibert) Tarore, G. Y. (Grace) Malingkas, and D. R. (D) Walangitan, "Pengendalian Waktu Dan Biaya Pada Tahap Pelaksanaan Proyek Dengan Menggunakan Metode Nilai Hasil (Studi Kasus : Proyek Lanjutan Pembangunan Gedung Pip2b Kota Manado)," *J. Sipil Statik*, vol. 1, no. 1, p. 131571, 2012, Accessed: Mar. 12, 2021. [Online]. Available: https://www.neliti.com/publications/131571/.

[6] I. Widiasanti and Lenggogeni, *Manajemen Konstruksi*. 2013.

[7] E. R. (Ezekiel) Iwawo, J. (Jermias) Tjakra, and P. A. (Pingkan) Pratasis, "Penerapan Metode Cpm Pada Proyek Konstruksi (Studi Kasus Pembangunan Gedung Baru Kompleks Eben Haezar Manado)," *J. Sipil Statik*, vol. 4, no. 9, p. 139935, 2016, Accessed: Mar. 12, 2021. [Online]. Available: https://www.neliti.com/publications/139935/.

[8] J. S. (Juan) Simatupang, A. K. (A) Dundu, and M. (Mochtar) Sibi, "Pengaruh Percepatan Durasi Terhadap Waktu Pada Proyek Konstruksi (Studi Kasus : Pembangunan Persekolahan Eben Haezar Manado)," *J. Sipil Statik*, vol. 3, no. 5, p. 140219, 2015, Accessed: Mar. 12, 2021. [Online]. Available: https://www.neliti.com/publications/140219/.

[9] H. Olivieri *et al.*, "Survey Comparing Critical Path Method, Last Planner System, and Location-Based Techniques," *J. Constr. Eng. Manag.*, vol. 145, no. 12, p. 04019077, Sep. 2019, doi: 10.1061/(ASCE)CO.1943-7862.0001644.

[10] A. Abdurrasyid, L. Luqman, A. Haris, and I. Indrianto, "Implementasi Metode PERT dan CPM pada Sistem Informasi Manajemen Proyek Pembangunan Kapal," *Khazanah Inform. J. Ilmu Komput. dan Inform.*, vol. 5, no. 1, pp. 28–36, Jun. 2019, doi: 10.23917/KHIF.V5I1.7066.

[11] F. H. Lermen, M. de F. Morais, C. Matos, R. Röder, and C. Röder, "Optimization of Times and Costs of Project of Horizontal Laminator Production Using Pert/Cpm Technical," *Indep. J. Manag. Prod.*, vol. 7, no. 3, pp. 833–853, 2016, doi: 10.14807/ijmp.v7i3.423.

[12] A. M. Aliyu, "Project Management using Critical Path Method (CPM): A Pragmatic Study," *Glob. J. Pure Appl. Sci.*, vol. 18, no. 3–4, pp. 197–206, Mar. 2013, doi: 10.4314/gjpas.v18i3-4.11.

[13] T. Hegazy and W. Menesi, "Critical Path Segments Scheduling Technique," *J. Constr. Eng. Manag.*, vol. 136, no. 10, pp. 1078–1085, Sep. 2010, doi: 10.1061/(ASCE)CO.1943-7862.0000212.

[14] H. Olivieri, O. Seppänen, and A. Denis Granja, "Improving workflow and resource usage in construction schedules through location-based management system (LBMS)," *Constr. Manag. Econ.*, vol. 36, no. 2, pp. 109–124, Feb. 2018, doi: 10.1080/01446193.2017.1410561.

[15] M. A. Ammar, "LOB and CPM Integrated Method for Scheduling Repetitive Projects," *J. Constr. Eng. Manag.*, vol. 139, no. 1, pp. 44–50, Apr. 2012, doi: 10.1061/(ASCE)CO.1943-7862.0000569.

[16] A. W. (Apri) Laksana, H. S. (Heri) Prasetyo, M. A. (Mochammad) Wibowo, and A. (Arif) Hidayat,

"Optimalisasi Waktu Dan Biaya Proyek Dengan Analisa Crash Program," *J. Karya Tek. Sipil S1 Undip*, vol. 3, no. 3, pp. 747–759, 2014, Accessed: Mar. 12, 2021. [Online]. Available: https://www.neliti.com/publications/106820/.

[17] S. Zareei, "Project scheduling for constructing biogas plant using critical path method," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 756–759, Jan. 2018, doi: 10.1016/J.RSER.2017.08.025.

[18] "Analisa Penerapan Manajemen Waktu Dan Biaya Pada Proyek Pembangunan Hotel BW Luxury Jambi." Accessed Mar. 12, 2021. [Online]. Available: https://id.scribd.com/document/402353239/Analisa-Penerapan-Manajemen-Waktu-Dan-Biaya-Pada-Proyek-Pembangunan-Hotel-Bw-Luxury-Jambi .

[19] D. Trietsch and K. R. Baker, "PERT 21: Fitting PERT/CPM for use in the 21st century," *Int. J. Proj. Manag.*, vol. 30, no. 4, pp. 490–502, May 2012, doi: 10.1016/J.IJPROMAN.2011.09.004.

[20] M. Engwall, "PERT, Polaris, and the realities of project execution," *Int. J. Manag. Proj. Bus.*, vol. 5, no. 4, pp. 595–616, Sep. 2012, doi: 10.1108/17538371211268898/FULL/XML.

[21] D. Caesaron and A. Thio, "Analisa Penjadwalan Waktu dengan Metode Jalur Kritis dan PERT pada Proyek Pembangunan Ruko (Jl. Pasar Lama No. 20 Glodok)," *JIEMS (Journal Ind. Eng. Manag. Syst.*, vol. 8, no. 2, Mar. 2017, doi: 10.30813/JIEMS.V8I2.124.

[22] S. A. NISAR, K. YAMAMOTO, and K. SUZUKI, "Resource-Dependent Critical Path Method for Identifying the Critical Path and the 'Real Floats' in Resource-Constrained Project Scheduling," *J. Japan Soc. Civ. Eng. Ser. F4 (Construction Manag.*, vol. 69, no. 4, p. I_97-I_107, 2013, doi: 10.2208/JSCEJCM.69.I_97.

[23] W. Lipke, "Earned Schedule Contribution to Project Management," *PM World J.*, vol. I, no. Ii, pp. 1–19, 2003.

[24] E. Gardjito, "Pengendalian Jadwal Dan Anggaran Terpadu Dengan Metode Earned Value Analysis Pada Pekerjaan Konstruksi," *UKaRsT*, vol. 1, no. 1, p. 19, 2018, doi: 10.30737/ukarst.v1i1.82.

[25] P. Ballesteros-Pérez, E. Sanz-Ablanedo, D. Mora-Melià, M. C. González-Cruz, J. L. Fuentes-Bargues, and E. Pellicer, "Earned Schedule min-max: Two new EVM metrics for monitoring and controlling projects," *Autom. Constr.*, vol. 103, pp. 279–290, Jul. 2019, doi: 10.1016/J.AUTCON.2019.03.016.

[26] P. A. de Andrade, A. Martens, and M. Vanhoucke, "Using real project schedule data to compare earned schedule and earned duration management project time forecasting capabilities," *Autom. Constr.*, vol. 99, pp. 68–78, Mar. 2019, doi: 10.1016/J.AUTCON.2018.11.030.

[27] Y. A. Messah, L. H. P. Lona, and D. A. T. Sina, "Pengendalian Waktu Dan Biaya Pekerjaan Konstruksi Sebagai Dampak Dari Perubahan Desain," *J. Tek. Sipil*, vol. 2, no. 2, pp. 121–132, Sep. 2013, doi: 10.35508/JTS.2.2.121-132.

[28] A. Susanty, A. L. Pekerti, and D. P. Sari, "Analisis Kinerja Proyek Pembangunan Rumah Sakit Banyumanik Ii Dengan Menggunakan Earned Value Analysis (Eva) Dan Project Evaluation Review Technique (Pert).," *J@ti Undip J. Tek. Ind.*, vol. 11, no. 2, pp. 61–72, Jun. 2016, doi: 10.14710/JATI.11.2.61-72.

[29] B. Koke and R. C. Moehler, "Earned Green Value management for project management: A systematic review," *J. Clean. Prod.*, vol. 230, pp. 180–197, Sep. 2019, doi: 10.1016/J.JCLEPRO.2019.05.079.

[30] Y. A. Effendi and R. Sarno, "Non-linear optimization of critical path method," *Proceeding - 2017 3rd Int. Conf. Sci. Inf. Technol. Theory Appl. IT Educ. Ind. Soc. Big Data Era, ICSITech 2017*, vol. 2018-January, pp. 90–96, Jul. 2017, doi: 10.1109/ICSITECH.2017.8257091.

[31] J. Hasil Penelitian dan Karya Ilmiah and A. Ilma, "Analisa Penjadwalan Proyek Menggunakan PDM dan Pert Serta Crash Project (Studi kasus: Pembangunan Gedung Main Power House PT. Adhi Karya)," *J. Tek. Ind. J. Has. Penelit. dan Karya Ilm. dalam Bid. Tek. Ind.*, vol. 2, no. 1, pp. 31–43, Jun. 2016, doi: 10.24014/JTI.V2I1.5061.

[32] G. P. Arianie and N. B. Puspitasari, "Perencanaan Manajemen Proyek Dalam Meningkatkan Efisiensi Dan Efektifitas Sumber Daya Perusahaan (Studi Kasus : Qiscus Pte Ltd)," *J@ti Undip J. Tek. Ind.*, vol.

12, no. 3, pp. 189–196, Sep. 2017, doi: 10.14710/JATI.12.3.189-196.

[33] D. Bryde, C. Unterhitzenberger, and R. Joby, "Conditions of success for earned value analysis in projects," *Int. J. Proj. Manag.*, vol. 36, no. 3, pp. 474–484, Apr. 2018, doi: 10.1016/J.IJPROMAN.2017.12.002.

[34] L. M. Naeni, S. Shadrokh, and A. Salehipour, "A fuzzy approach for the earned value management," *Int. J. Proj. Manag.*, vol. 29, no. 6, pp. 764–772, Aug. 2011, doi: 10.1016/J.IJPROMAN.2010.07.012.

[35] A. Czemplik, "Application of Earned Value Method to Progress Control of Construction Projects," *Procedia Eng.*, vol. 91, pp. 424–428, Jan. 2014, doi: 10.1016/J.PROENG.2014.12.087.

[36] J. Colin, A. Martens, M. Vanhoucke, and M. Wauters, "A multivariate approach for top-down project control using earned value management," *Decis. Support Syst.*, vol. 79, pp. 65–76, Nov. 2015, doi: 10.1016/J.DSS.2015.08.002.

[37] M. C. P. Sing, D. J. Edwards, H. J. X. Liu, and P. E. D. Love, "Forecasting Private-Sector Construction Works: VAR Model Using Economic Indicators," *J. Constr. Eng. Manag.*, vol. 141, no. 11, p. 04015037, Jun. 2015, doi: 10.1061/(ASCE)CO.1943-7862.0001016.

[38] A. De Marco and T. Narbaev, "Earned value-based performance monitoring of facility construction projects," *J. Facil. Manag.*, vol. 11, no. 1, pp. 69–80, Feb. 2013, doi: 10.1108/14725961311301475/FULL/XML.

[39] H. L. Chen, W. T. Chen, and Y. L. Lin, "Earned value project management: Improving the predictive power of planned value," *Int. J. Proj. Manag.*, vol. 34, no. 1, pp. 22–29, Jan. 2016, doi: 10.1016/J.IJPROMAN.2015.09.008.

[40] S. Babar, M. J. Thaheem, and B. Ayub, "Estimated cost at completion: integrating risk into earned value management," *J. Constr. Eng. Manag.*, vol. 143, no. 3, Mar. 2017, doi: 10.1061/(ASCE)CO.1943-7862.0001245.

[41] A. Baldwin and D. Bordoli, *Handbook for Construction Planning and Scheduling*. Wiley Blackwell, 2014.