



Earned Resource Management” A new model for estimate project duration in construction projects”

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Abstract

During the past decades, various models were presented to estimate project duration but, we usually face with this problem that why the estimated values for finish time of the activities and the project don't match with the actual values and there is always a huge gap between the estimated finish time of the project and the actual finish time of the project. The oldest method that has been widely used in the past decades is the Earned Value Management (EVM) methodology, which estimates the completion time of the project based on cost indicators. During the past years, researchers have developed new models such as Earned Duration Management (EDM), Earned Schedule Management (ESM) that each of them has tried to reduce the prediction error by focusing on the indicators presented in their proposed models. In this research, the Earned Resource Management (ERM) model has been developed, which present indicators for measuring the performance of activities based on the resources provided for the implementation of project activities, as well as the progress of project activities using these resources. It is a more suitable basis for evaluating how activities are implemented and also estimating their finish time. The proposed model is implemented on a construction project and the results show that the Mean absolute percentage error (MAPE) is about 3.12%, at the end of the project which is lower than other presented methods.

Keywords: Project Management, Estimate project Duration, Construction Project. Resource Management

Paper Type: Original Research

1. Introduction

One of the key aspects that a project manager concentrates on is the accuracy of the duration forecasts (Yang and Chen, 2024). Most of construction projects deal with delays, but how to estimate it and the accuracy of the estimation is important. Due to the inherent dynamic and uncertain nature of projects, unexpected events may arise, evolve and eventually sometimes fade away while the project is in progress. This project risk often propagates through an implicit structure consisting of causal paths and damages the project, resulting in huge delays and cost overruns (Ünsal-Altuncan and Vanhoucke, 2024). In the execution of various projects, the completion of the project on a specific date and determined budget have consistently been crucial topics. Over the years, numerous articles have addressed finding the best methods for estimating these factors, and various models have been proposed in this field. In research conducted in past decades, researchers have predominantly focused on financial predictions, particularly in finding models for estimating the final project budget and usually these models have been used for predicting the project duration. The actuality of project management is grounded in socio-material actions that are characterized by human behaviors (Bosch et al., 2023) often referred to as soft skills and prescribed for the purpose of measuring individuals, activities, and the use of resources against pre-defined time, cost, and quality constraints (Jonas et al., 2012). Given the importance of timely project completion and the efficient utilization of projects, the ability to accurately predict the project completion time is a necessary for project managers. Therefore, in recent years, innovative and novel solutions and approaches have been proposed to enhance the improvement of activities management and the accuracy of predicting project durations, independently of project costs. These approaches strives to improve the accuracy and precision of predictions.

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2. Literature Review

Based on a review of previous research in prediction of project completion, three methodologies, namely EVM, ESM, and EDM, have been generally proposed. These methodologies have been relatively endorsed by other researchers and are utilized in various studies. In the following, we elaborate on each of these aspects.

2.1. Earned Value Management

The ability to accurately forecast a project's final duration and cost is essential to successful project management. The technique of earned value management (EVM) is considered to provide an effective methodology for obtaining such forecasts (Batselier and Vanhoucke, 2015). The oldest and most prevalent methodology that took shape in the 1960s is the EVM method, which was the only widely accepted and endorsed methodology by researchers until the early 20th century (Colin and Vanhouke, 2014). EVM is a project management approach that can enhance the probability of project success. It is applied widely across different industry sectors (Aramali and Sanboskani, 2022). Since research during those years primarily focused on predicting project costs and cash flow, and the criteria and variables of this method were based on project cost information, it became the best and only method used by researchers. In most proposed models, the information used for predicting project completion costs and durations has been related to project financial information, mainly based on the EVM methodology and its calculations and metrics. Novel and diverse models have been proposed based on these methodologies. From the early 20th century, with a growing emphasis on predicting project completion duration, some researchers found that this method is not suitable for predicting project completion duration. Numerous studies have highlighted the problems and disadvantages of this method in estimating project completion duration. Due to extensive research in this area, two methodologies, ESM and EDM, have been introduced and developed by researchers in recent years, attempting to use data related to project duration and activities for estimating completion duration more effectively than models based on EVM. The Earned Schedule Management (ESM) methodology and Earned Duration Management (EDM) methodology were introduced and developed in this field by researchers in recent years. They sought to utilize data related to project and activities duration to estimate completion duration more effectively than models based on EVM. In comparison with models based on EVM, these methodologies demonstrated better performance in predicting project duration. Earned Value Management (EVM) as a standardized method for measuring project performance was developed by the United States Department of Defense in the 1960s (Vanhouke, 2023). Earned Value Management is a management methodology used to integrate scope, schedule, and resources to measure the tangible performance and progress of a project and predict project outputs. The use of Earned Value Management in the early stages of project planning increases the credibility of scheduling and budgeting and serves as an excellent tool for validating project scope assumptions and project baselines (Practice standard for earned value management, second edition, 2011). EVM measures the actual physical progress of the project in terms of the three main elements of project management: scope, schedule, and cost (Vandevoorde and Vanhouke, 2006). This method calculates the amount of work completion in the project, the project completion duration, and the project completion cost. It helps manage project risks by evaluating and controlling project progress based on financial assessment criteria. Figure 1 illustrates the general concept of earned value. Although this method is designed for tracking time and cost, most of its research has been on cost. Nevertheless, EVM has introduced two well-known scheduling performance indices called Schedule Variance (SV) and Schedule Variance Index (SPI) to measure project progress. The formulas for calculating these indices are as follows:

$$SV = EV - PV$$

$$SPI = EV/PV$$

Planned Value (PV) often refers to Budgeted Cost for Work Scheduled (BCWS), which is equivalent to the planned budget for scheduled work. Earned Value (EV), on the other hand, refers to Budgeted Cost for Work performed (BCWP), indicating the earned value of work performed. SV indicates the deviation of work performed against the planned work and is measured in monetary units. This has been highlighted in various articles as a weakness of EVM in predicting project completion time. If $SV < 0$, it means that the value of work performed is less than the planned work, indicating that the project is behind schedule. If $SV > 0$, it means that the earned value of work performed is greater than the planned value, indicating that the project is ahead of schedule. If $SV = 0$, it means that the project is progressing according to the plan, and at the end of the project, $EV = PV = BAC$, indicating the planned budget for project completion. Therefore, SV is always equal to zero at the end of the project, which is another criticism of the EVM methodology. Another index introduced in the field of time performance measurement by EVM is SPI, indicating the ratio of earned value to planned value. SPI is a dimensionless index indicating the efficiency and effectiveness of work performed.

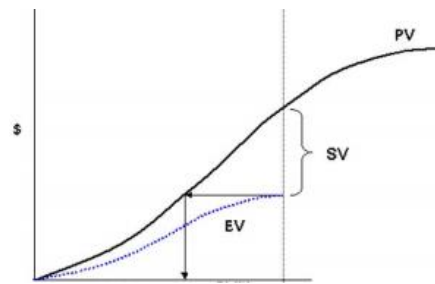


Figure 1: Earned Value Management concept

If $SPI < 1$, it indicates less efficiency compared to the planned value.

If $SPI > 1$, it indicates greater efficiency compared to the planned value.

If $SPI = 1$, it indicates equal efficiency compared to the planned value.

At the end of the project, SPI is always equal to 1, which is a weakness of this model that researchers consistently criticized in terms of the results obtained from this model.

2.2 Earned Schedule Management

Lipke (2003) introduced the concept of Earned Schedule. An extension to EVM has emerged which provides reliable, useful schedule performance information. The extension is earned schedule (ES). The concept of ES is shown in figure 2. In this methodology, the earned value at a specific time is tracked based on being ahead or behind the project's scheduled timeline. Then, the intersection point on the earned value axis is moved to the time axis to calculate the earned time. Therefore, the earned value is determined based on when it is earned according to the project's schedule. In this way, the concept of earned value transforms into earned time and the actual project performance is compared to the desired time performance. The corresponding time performance metrics are defined as follows:

$$SV(t) = ES - AT$$

$$SPT(t) = \frac{ES}{AT}$$

In which AT refers to the actual time of the project. In comparison with SV, $SV(t)$ is expressed based on a unit of time, making its interpretation simpler.

If $SV(t) < 0$, it indicates the number of time units of delay in the project.

If $SV(t) > 0$, it indicates the number of time units ahead of the scheduled project timeline.

The behavior of $SV(t)$ at the end of the project is equal to the precise difference between actual time and the planned schedule, while in the EVM method, this value is always zero at the end of the project. Similarly, $SPT(t)$ at the end of the project indicates the final time performance of the project, whereas in the EVM method, this value is always equal to one at the end of the project. Other studies use calculations for estimating unweighted ESM. (Batselier and Vanhoucke, 2015a, Guerrero et al., 2014). In another study, Lipke (2009) utilized statistical predictions to enhance the reliability of the ESM model in forecasting project cost and completion time. Additionally, in other research conducted by Henderson (2005) the validation of the ES method demonstrated its credibility through the application of this model in six projects.

W. Lipke et al. / International Journal of Project Management 27 (2009) 400–407

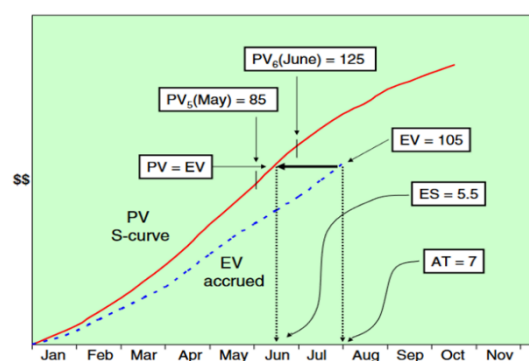


Figure 2. Earned schedule concept

Elshaer (2013) focused on examining and analyzing the sensitivity of project information in predicting project duration. He employed the Earned Schedule Method (ESM) for project duration prediction and demonstrated that, on average, the outcomes of this method are more favorable compared to other approaches. However, the research concluded that the reliability of this method is higher at higher levels of project breakdown structure. In some other research, it has been shown that ES, on average, is a better predictor of final duration than other commonly used EVM-based schedule forecasting methods (Anbari, 2003, Vanhoucke and Vandevoorde, 2006)

2.3. Earned Duration Management

Jacob (2003) presented a new model based on duration performance criteria and expanded this model with Kane (2004), which is called Earned Duration Management (EDM). In this model, the earned duration is calculated based on the following formula:

$$ED = AD * SPI$$

In which AD refers to the actual duration of the project.

The project duration calculates based on this formula:

$$EAC(t) = AD + (PD - ED) / PF$$

where PF is calculated in three different modes:

If $PF = 1$

$$EAC(t) = AD + (PD - ED) / 1 \rightarrow EAC(t) = PD + AD * (1 - SPI)$$

If $PF = SPI$

$$EAC(t) = AD + (PD - ED) / SPI \rightarrow EAC(t) = PD / SPI$$

If $PF = SCI$

$$EAC(t) = AD + (PD - ED) / SCI \rightarrow EAC(t) = PD / SCI + AD * (1 - 1/CPI)$$

Also, Also, another research was conducted by Khamooshi and Golfeshani (2013) in this field, in which time and cost measurement criteria were separated, and a number of indicators were developed to measure the progress and performance of time and cost. In another study conducted by Vanhoucke and Batselier (2015), the prediction results of ESM and EDM methods were compared on 23 real projects. The comparison index for the accuracy of the above methods was Mean Absolute Percentage Error (MAPE), which has been used in many similar articles and research studies. De Andrade and Vanhoucke (2017) performed a comparative analysis between time predictions using ES and EDM. Khamooshi and Abdi (2017) applied the EDM to predict project duration with exponential smoothing techniques. Ghanbari et al. (2017a,2017b) applied fuzzy techniques to solve uncertainty problems by applying the EDM. Acebes et al. (2022) present how EDM can be applied to monitor and control stochastic projects. To explain the methodology.

3. Proposed Model

A few models have been proposed for predicting the project duration, most of which utilize EVM parameters, all based on cost. Over the past years, some predictive models, such as ESM and EDM, have been introduced based on project time performance. However, these models often overlook the issues of resource efficiency and the performance of resources employed in project execution. Project resource management is a knowledge area in project management that includes processes of identifying, acquiring, and managing the resources needed for the successful completion of the project, it is crucial to transparently determine the type of resources and their required quantities (PMBOK® Guide-Sixth Edition, 2017). As illustrated in Figure 3, we aim to present a new model in this paper to estimate the project completion duration using indicators related to resource management.

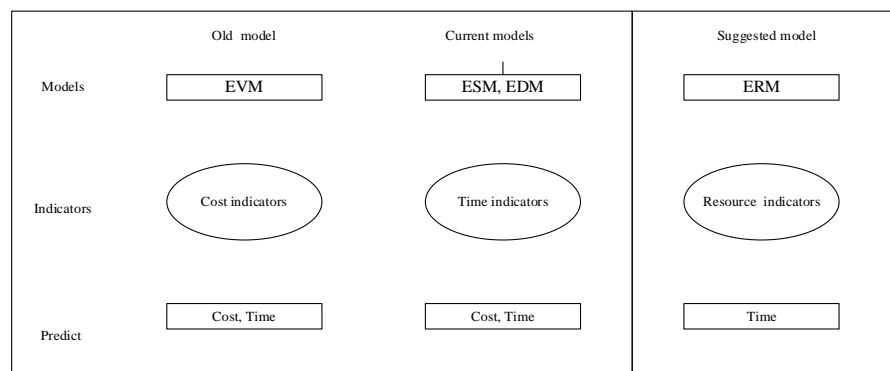


Figure 3. Conceptual Model of the Proposed Methods

These indicators are designed by considering the resource management and performance of employed resources in project activities throughout the project's duration, that help us to have a more accurate estimate of the project's completion. One common categorization for resources is based on renewable resources, non-renewable resources, and dual-constraint resources. Renewable resources are those available from period to period, including human resources, machinery and equipment, and workspace. Non-renewable resources are available in a specific and predetermined amount over the project's duration, such as money, consumable materials, and supplies. Dual-constraint resources are limited in each time period, such as limited financial resources in each time period or constrained human resources as examples of this categorization (Demeulemeester and Herroelen, 2022). Creating a model that can provide an accurate prediction of the completion date of activities and the overall project based on all the resources employed in the project is challenging. Typically, precise information about the amount of resources used in projects is not readily available, making such prediction almost impossible. However, it is possible to forecast the project completion date and its activities based on information related to the primary resources planned and utilized in different time periods of the project. Based on the classification of projects in terms of their nature of execution, different resources in each project can be considered as important and key resources. For example, in software projects, specialized software engineers can play a crucial and vital role in the success and timely completion of the project. In construction projects, human resources are essential and vital in project execution. Although human resources may not have a significant cost impact on construction projects, the management of human resources and their performance have a substantial influence on the success and timely completion of the project. In the proposed model, the researchers aim to develop a new model based on the resources used in the project, allowing for a more accurate estimation of the project's completion date. Key performance indicators based on the amount of resources employed in different time periods for each activity are presented in the model. Using these indicators, a model for predicting the completion date of activities is proposed. Definitions and key performance indicators utilized in the proposed model are provided in Table 1. Total Planned Resource for an activity, represented by PR, refers to the amount of resources allocated for the execution of an activity at the beginning of the project during the planning phase. The Actual Resource for an activity, represented by AR, is the actual amount of resources employed in an activity. The Earned Resource, represented by ER in this model, indicates how much of the planned resources we have obtained based on the progress of the activity. To calculate ER, the following formula is utilized:

$$ER = \% \text{ Complete} * PR$$

In which %complete represents the actual progress percentage of the activity. The Resource Performance Index (RPI) is, in fact, a key indicator for evaluating the status of project activity execution, indicating how project managers stand in terms of deploying their primary resources compared to the planned schedule. The formula for calculating this index is:

$$RPI = ER/AR.$$

If this index is greater than one, it indicates that project managers have performed better than planned in deploying their primary resources for activity execution. Conversely, if this number is less than one, it indicates a deficiency in the performance of managers in deploying resources.

Table 1. ERM key metrics and definition

Metrics	Definition	Metrics	Definition
PR	Planned resource	ER	Earned resource
PD	Planned duration	ED	Earned duration
AR	Actual resource	RPI	Resource Performance Index
AD	Actual duration	DPI	Duration Performance Index

The Planned duration for an activity, represented by PD, refer to the time allocated for each activity at the beginning of the project scheduling process. The Actual Duration, represented by AD, is an indicator of the actual time spent on an activity. Additionally, Earned Duration, represented by ED, refer to the time obtained based on the progress and completion of the activity, is calculated using the formula:

$$ED = \% \text{ Complete} * PD.$$

Duration Performance Index is another key indicator for evaluating the status of project activity execution in terms of time. This index illustrates how project managers stand in terms of time execution compared to the planned schedule. DPI is calculated using the formula:

$$RPI = ED/AD$$

If this index is greater than one, it indicates that project managers are completing the activity in a shorter time compared to the initial project schedule, demonstrating better performance than the planned schedule.

Furthermore, if this number is less than one, it indicates a deficiency in the performance of managers in carrying out project activities compared to the initial schedule. To perform calculations for different activities, index i is considered for each activity. Additionally, to calculate the defined indices for each time period, index t is considered for each time period. For example, RPI_{it} represents the resource performance index for activity i in time period t . Given that the PF index in the proposed model is calculated using different methods in various situations, in this section, we explain its different. If the activity has not yet started, in this scenario:

$$PF_i(t) = 1$$

Considering that the activity has not started, we therefore adhere to the planned schedule for the activity and assume that the activity is being executed according to the planned schedule. If the activity is completed, in this scenario:

$$PF_i(t) = DPI_i(t)$$

Considering that the activity has been completed in past periods, the time performance index is the best indicator for this activity. If this index is less than one, it indicates that the above activity had weaker performance compared to the planned schedule and took more time than the planned duration. If it is greater than one, it shows that the execution of the activity is better than the initial project planning. If this number is equal to one, it indicates that the activity has been completed according to the planned schedule. If the activity is in progress and has not yet been completed, in this scenario:

$$PF_i(t) = RPI_i(t) * (AD_i(t) / \text{Max}(AD_i(t), PD_i(t)))$$

In this situation, which has the most significant impact on predicting the duration of activities and the overall project, the performance index is calculated based on how project resources are utilized in each period, denoted as $RPI_i(t)$. The second part of calculating the performance index in this case addresses the time spent on the activity. In this case, if the work on the activity is completed during the available time for the activity, the second part of the calculation formula will be equal to one. Also, if the time spent on the activity is greater than the planned duration, this number will still be equal to one. Only if less time than planned is spent on the activity, this number will be less than one, indicating less efficiency in using the available time for the project. In calculating the performance index in this case, both resource efficiency and time efficiency are considered in predictions. Given the calculation of PF, in each period, predictions for the remaining duration of the activity and the total duration of the activity can be made based on the following formulas:

$$ETCD_i(t) = ((1 - \%APC_i(t)) * PD_i(t)) / PF_i(t)$$

In which APC refers to the actual percent complete of the project. In the calculation related to predicting the remaining duration until the end of the activity, the coefficient of the performance index calculated in various scenarios in the previous section is utilized. If the activity is completed, the remaining duration will be zero. Similarly, if the activity has not started, the duration is estimated based on the initial planning. During the activity, the remaining duration is predicted based on the performance index of resources and time efficiency. Finally, to predict the total duration of the activity, the following formulas are used:

$$EAC_i(t) = AD + ETC_i(t)$$

$$EF_i(t) = ACS + EAC_i(t)$$

In which EF refers to the Estimate Finish Date of the activity i in time period t . Also, ACS refers to Actual Start Date of the activity i in time period t . Using the above formula when the activity has started will predict the end date based on the actual start date of the activity. However, to forecast the end date of activities that have not yet started, it is necessary to predict their end date by considering the precedence relationships with other activities. Therefore, the forecast of the end date of activities is calculated based on the following formula:

$$EF_i(t) = EF_j(t) + ETCD_i(t)$$

Where the index j corresponds to the effective predecessor activity of activity i . In each period, the largest $EF_i(t)$ can be used to calculate the project's end date prediction.

4. Findings

To test the proposed model, data from a construction project, which has been used in other international scientific articles, was employed for comparing the results of the proposed model with other methods. Since the main focus of this model was on the amount of resources used in the project, and in construction projects, the most important resource is human labor, a project with planned and utilized human resource data was selected for testing the model. After reviewing over a hundred projects presented on the website <https://www.projectmanagement> which collects data from various projects, only one project with complete data on human resources planned and

utilized was identified with the code C2011-10. The information from this project was used in the proposed model. Based on the information from this project, which includes 34 activities and spans 46 weekly time periods, the proposed model was used to estimate the project's end date. Since the MAPE criterion is commonly used in most proposed models to assess the accuracy of the proposed model, this research also utilizes this criterion to evaluate the performance of the proposed model. The calculation of this criterion is based on the following formula:

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right|$$

In which:

A_t represents the actual value in period t .

F_t represents the predicted value in period t

Also n represents the number of forecast periods. In the proposed model, considering that we are predicting the project completion duration in each period, the value A_t is equivalent to the actual project completion duration, and the value F_t is calculated based on the proposed model in each period. (Batselier and Vanhoucke, 2017). By employing the formulas presented in the proposed model, the MAPE for the project was obtained as 3.12%, indicating a relatively acceptable statistic for predicting the project completion. Considering the use of the proposed model in the selected construction project, the completion duration of the project and MAPE are presented in table 2. the MAPE results is presented in figure 4. After 7th week, all of predictions is less than 4% and only in initiating phase of project, our prediction isn't reliable, but after that our predicting is accurate. Based on the results obtained from applying the model to the selected construction project, it can be demonstrated that if information about the resources used in projects is accessible, we can show to what extent the efficiency and effectiveness of resource utilization in projects directly impact project completion. Therefore, one of the important outcomes of the proposed model is the focus on the efficiency of human resources in projects and how their management and utilization efficiency directly affect project completion.

Table 2. Prediction Calculations for the Construction Project Completion Time

Week	Planned Duration	Total Duration	Predict Duration	MAPE	Week	Planned Duration	Total Duration	Predict Duration	MAPE
1	203	195	192	8.17%	22	203	195	209	2.97%
2	203	195	200	7.29%	23	203	195	208	2.43%
3	203	195	202	10.34%	24	203	195	207	2.14%
4	203	195	198	7.01%	25	203	195	207	2.03%
5	203	195	200	6.75%	26	203	195	204	0.55%
6	203	195	202	6.36%	27	203	195	203	0.15%
7	203	195	209	2.97%	28	203	195	204	0.37%
8	203	195	210	0.11%	29	203	195	207	1.75%
9	203	195	210	3.33%	30	203	195	207	2.20%
10	203	195	210	3.33%	31	203	195	208	2.46%
11	203	195	210	3.33%	32	203	195	208	2.46%
12	203	195	210	3.33%	33	203	195	208	2.55%
13	203	195	210	3.33%	34	203	195	208	2.41%
14	203	195	210	3.33%	35	203	195	208	2.53%
15	203	195	210	3.33%	36	203	195	209	3.17%
16	203	195	210	3.33%	37	203	195	198	2.71%
17	203	195	210	3.33%	38	203	195	201	0.99%
18	203	195	210	3.33%	39	203	195	206	1.48%
19	203	195	210	3.33%	40	203	195	204	0.49%
20	203	195	210	3.33%	41	203	195	203	0.00%
21	203	195	209	3.10%	Average				3.12%

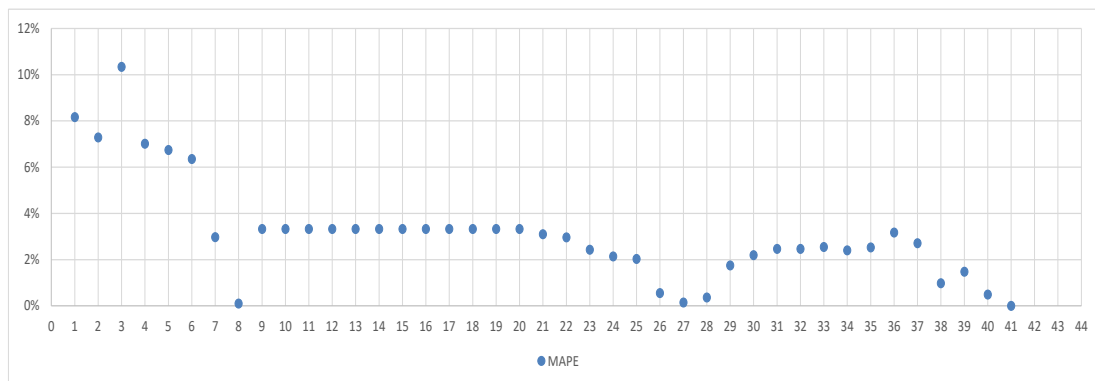


Figure 4. Prediction Error of Project Using MAPE Index

Another noteworthy aspect of this model is the utilization of information related to each individual project activity in predicting the overall project completion. In most proposed models, predictions are made based on the overall project status, while in this model, we were able to make an accurate estimate of the project completion time based on the actions taken in each activity and according to the performance indicators of each individual activity. Figure 4 illustrates the MAPE index for various activities in this project. As observed, out of the 33 defined activities in this project, only 3 activities have been predicted with an error greater than 7%, and the prediction of other activities using this model has very low error. One of the weaknesses of this model is the impact of prerequisite activities on estimating the project completion date. As shown in Table 2, in the tenth to sixteenth periods, due to the significant impact of predecessor activities, the project completion duration is predicted to be higher than the periods before and after. Finally, by performing one of the activities without considering the predecessor activity in the project execution, the project estimation in these periods is accepted with a relatively higher difference compared to other time periods. Therefore, incorrectly defining prerequisite relationships in projects is one of the factors that can significantly affect the accuracy of predictions based on the proposed model.

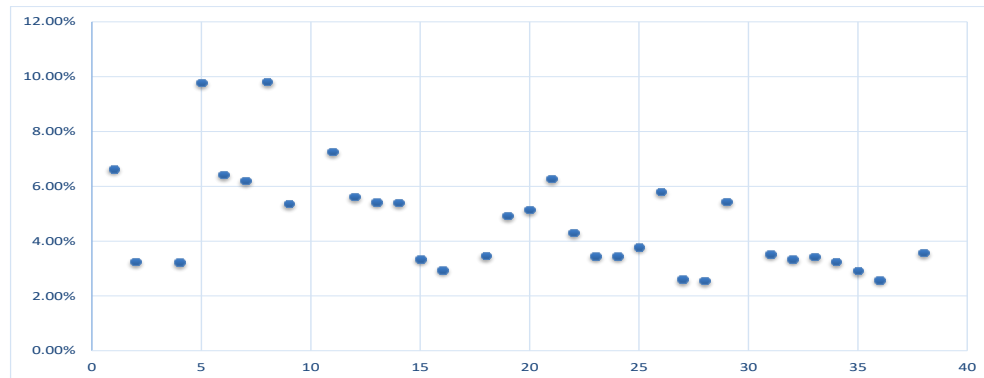


Figure 5. Prediction Error of Project Activities Using MAPE Index

5. Conclusion

The use of cost indices to predict project completion duration has been prevalent in past decades, with researchers relying on indices introduced in the Earned Value Management method for project time predictions. In recent years, various models have attempted to improve the accuracy of project completion duration predictions using time indices. In this study, we aimed to introduce a new model that, in addition to considering time indices, incorporates resource indices employed in project activities as one of the influential factors in predicting project completion. The impact of resource management performance and the efficiency of human resources in construction projects were also considered as essential elements in predicting project completion duration. By utilizing results from previous studies and incorporating resource indices, we managed to reduce the error rate in predicting project completion. Since the presented model is based on planned human resource management and utilized for project completion, we selected one of the construction projects used in international studies that had comprehensive information regarding the planned and employed human resources in different project periods. According to the results obtained from this research using MAPE metric, the proposed model demonstrates a 3.12% error rate in predicting the selected project, which is significantly lower than other existing models. The findings emphasize the significant impact of human resource management and the efficiency of human resources on project completion. In this study, we attempted to model and predict this reality. One of the challenges in predicting project completion using this approach is the lack of accurate data on the amount of resources employed in projects. Therefore, we were unable to test the model with a more extensive range of projects. It is recommended that future research compare the results of this model with other models by employing it in a larger number of projects.

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