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Unlocking the potential of Earned Value management in construction: A Comparative Study

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Unlocking the potential of Earned Value management in construction: A Comparative Study.

A THESIS SUBMITTED BY

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Declaration:

I, Mohamed Ashraf Mohamed, declare that this thesis titled, “Unlocking the potential of Earned Value management in construction: A Comparative Study.” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- In instances where I have referred to published works by other authors, proper attribution has consistently been provided.
- When incorporating direct quotes from the work of others, the source is consistently cited. Outside of these quotations, this thesis represents solely my independent work.
- I have duly recognized all primary sources of assistance.
- In cases where this thesis is founded on collaborative efforts involving others, I have distinctly delineated the specific contributions made by each collaborator and my own contributions.

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Abstract

The implementation of earned value management (EVM) in the Egyptian construction industry faces challenges when it comes to application, accuracy, and interpretability of results, with potential enhancements yet to be realized. In light of technological advancements, there is an opportunity to develop a controlled EVM approach for improved project management. The goal of this research is to enhance the application and accuracy of earned value techniques in Egyptian construction projects through a comprehensive evaluation of Earned Duration, Earned Schedule, and Planned Value methods. The key challenge that is addressed in this research lies in selecting an optimal technique considering the variations in accuracy based on project type and duration.

A comprehensive comparison of three earned value techniques the Earned Duration method, Earned Schedule method, and Planned Value method was conducted across 30 diverse construction projects in Egypt. Encompassing commercial, educational, industrial, renovation, and residential sectors from January 15, 2015, to December 30, 2023, the study evaluates the accuracy of these techniques in predicting project completion dates.

The research reveals that project type and duration significantly influence the choice of the most accurate earned value technique. Progress in renovation and residential projects the most accurate is the Earned Schedule method, while industrial, commercial, and educational projects lean towards the Earned Duration method. The inconsistency prompts the need for a systematic approach tailored to specific project characteristics.

Practical guidelines for selecting the most efficient technique based on project duration percentages are introduced, aiding project managers in informed decision-making for accurate project forecasting. However, the interplay of performance factors, including SPI and SCI, still requires a nuanced understanding. The research emphasizes the challenge of reconciling the overall effectiveness of the Earned Duration method with nuanced performance variations under different factors and project types.

In conclusion, this research contributes a comprehensive and applicable framework to assist project managers in selecting the most efficient earned value technique for precise project forecasting in the unique context of Egyptian construction projects.

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Chapter 1: Introduction

1.1. General Introduction

To monitor the project is to compare the current with the planned situation, determining if the costs and the schedule are progressing according to plan, in order to take corrective action when needed. Any project with a considerable cost overrun and schedule delay typically gets in trouble at its beginning as indicated by Alvarado (2004). In addition, project managers do not realize this problem until late in the project when their ability to recover the project to achieve its planned objectives diminishes.

EVM is the most used multi-dimensional project control method, as it integrates time and cost (Rozeneset al., 2006). The Project Management Body of Knowledge (PMBOK) defines control as "comparing actual performance with planned performance, analyzing variances, assessing trends to effect process improvements, evaluating possible alternatives, and recommending appropriate corrective action as needed." (PMI, 2004, p. 355). In another study evaluating the reliability of EVM conducted by Mahdi et al. in 2016, it was discovered that among the EVMs assessed in the sample cluster, time schedules were identified as the most influential. Additionally, the study noted that while quality also played a role, its impact was not as substantial as the time schedule, yet still considered significant. Keeping under budget and ahead of time schedule are key measures for project success. The executed work compared with planned work is considered a work performance indicator, also the cost spent compared with the cost remaining can be taken into consideration as a work performance indicator. DE Marco et Timur, (2013) stated that indicators are essential management tools in monitoring and evaluating project activities, as they allow the achievement of goals to be monitored as well as advances and improvements in quality to be identified.

The EVM method has been used for numerous projects during the past 40 years (Lipke, 2008). This method had a favorable impact on various aspects associated with project outcomes, including but not limited to enhanced planning, risk evaluation, monitoring, reporting, and controlling. Nevertheless, few researchers have shown some studies regarding the analysis and evaluation of time and cost performance stability while taking into account the quality of work. Despite the fact that EVM has been employed by numerous companies for over 35 years as a means to forecast time and cost outcomes, numerous studies, including (Lipke et al, 2009), have identified weaknesses in its effectiveness.

The evaluation of project performance involves analysing earned value indicators related to cost, schedule, and scope. These aspects, are known as the iron triangle as recognized by the Project Management Institute (PMI), are crucial for ensuring project efficiency (Project Management Institute, 2017). To derive the earned value indicator, it is imperative to quantify activities in terms of cost and establish completion dates for each task. As highlighted by Vargas (2003), the EVM technique intricately links cost, schedule, and scope in project management.

1.2. Problem Statement

Since the development of EVM, the implementation of this approach is yet questioned in the construction industry in Egypt and potential improvements are yet on the verge. There are various studies in the literature review that discussed the potential limitations of EVM and the urgency of further investigation to enhance the process and outcomes of using EVM in the project (Mahdi et al., 2018). Some of the limitations were the complexity of the process, lack of sufficient accuracy, and the process is classified to be time-consuming (CanCandido et al., 2014). Therefore, with the current advancement in the tools and technology used in the construction sector, there is a prospective opportunity to invent well controlled EVM approach that can improve the overall management of the project regardless of its circumstances and challenges.

Luis Felipe Cândido et al. (2014) investigated conceptual problems and implementation difficulties associated with EVM. Through a case study on a construction project utilizing EVM for planning and control, they identified four major issues. The EVM approach, they found, falls short in supporting lean construction applications. Two notable problems include the neglect of the mobilization of resources phase and the absence of consideration for construction indirect costs. In their conclusion, the researchers asserted that EVM merely extends the traditional approach of measuring physical and financial progress over time. This narrow approach is insufficient to provide a comprehensive managerial tool, as became clear through the analyses of the building project under consideration. The main advantage of this technique is its relative simplicity and that it only requires the kind of information (activity percentages of completion and actual costs mostly) that is gathered for other purposes during the project execution. The biggest disadvantage, which has apparently remained out-of-sight for most practitioners and researchers alike is that EVM is a technique that measures ‘amount of work performed’, not time deviations.

Put it in simple words, EVM measures the differences between earned value (EV) and planned value (PV) (for time deviations) or between EV and actual cost (AC) (for cost deviations). If EV is greater that either PV or AC, the project is doing well in time or cost, respectively. But EV increases as more activities are finished, irrespective of whether the order of execution was the most appropriate. The reasonable question then is: are the activities being finished so far, the ones that will lead to achieving the project duration we planned originally? EVM cannot tell. Indeed, if we deviate significantly from the project schedule, complementary indices like the p-factor (Lipke 2004), which measure schedule adherence, inform us about the risk of rework but they still fail to anticipate what (negative) time deviations can be expected.

EVM is therefore, a technique that works perfectly in the cost dimension (Ballesteros-Pérez et al. 2015, Ballesteros-Pérez et al. 2016), as all activities contribute to the total project cost according to their respective budgets. But that is not the case for time deviations. Activities need to happen in specific order to achieve a particular duration. According to Fleming and Koppelman (2010), EVM techniques are difficult to be applied to dynamic construction projects and do not add much value to project execution, especially when: 1) There is absence of adequate project planning and documentation, 2). The construction schedule is compounded by considering the resource constraints such as resource availability limits and multiple calendars, iii. Activity and project delays encountered during project executions, iv. There is no EVM analyst or specialist within the project team. Some problems that may impede the implementation of EVM as specified by Kim et al. (2003) such as: - High cost, complicated and burdensome paperwork - Poor understanding of EVM - Distrust and conflict between project managers, project consulting and government -Pressures to report only good news.

The critical need for effective earned value techniques in the construction industry, specifically focusing on project forecasting accuracy across diverse construction projects in Egypt Furthermore, the variation in the most accurate technique based on project type and duration introduces complexity in selecting the optimal method. Renovation and residential projects favor the Earned Schedule method, while industrial, commercial, and educational projects consistently lean towards the Earned Duration method. This inconsistency prompts the need to identify a systematic approach for method selection tailored to specific project characteristics.

In essence, the problem revolves around reconciling the overall effectiveness of the Earned Duration method with the nuanced performance variations under different performance factors and project types. The challenge is to provide a comprehensive and applicable framework that assists project managers in selecting the most efficient earned value technique for precise project forecasting, considering the unique characteristics of each construction project in the Egyptian context.

1.3. Research Goal and Objectives

The goal of this research is to enhance the application and accuracy of earned value techniques in Egyptian construction projects through a comprehensive evaluation of Earned Duration, Earned Schedule, and Planned Value methods. The research seeks to understand variations in technique accuracy based on project type, particularly focusing on preferences for specific methods in different project categories. Key goals include developing a systematic approach for selecting the most accurate technique, assessing and refining practical guidelines for decision-making, and exploring the impact of performance factors like SPI and CPI. Ultimately, this will promote the adoption of earned value techniques for improved project forecasting in the Egyptian construction sector.

The objectives of this research are the following:

1. Evaluate the effectiveness of earned value techniques in forecasting project completion dates across diverse construction projects in Egypt.
2. Investigate the variations in the accuracy of earned value techniques based on project type and duration, specifically examining the preference for the Earned Schedule method in renovation and residential projects and the consistent preference for the Earned Duration method in industrial, commercial, and educational projects.
3. Develop a systematic approach for selecting the most accurate earned value technique tailored to specific project characteristics, aiming to address the complexity introduced by the varying preferences for techniques across different project types.
4. Assess the practical guidelines introduced in the thesis for choosing the most efficient technique based on project duration percentages.
5. Examine the interplay of performance factors, including Schedule Performance Index (SPI) and Cost Performance Index (CPI) for different project types, to gain a more nuanced understanding of their impact on the accuracy of earned value techniques.
6. Develop a comprehensive and applicable framework that reconciles the overall effectiveness of the Earned Duration method with nuanced performance variations under different performance factors and project types, aiming to provide practical guidance for project managers in the Egyptian construction context.

1.4. Research methodology

The proposed methodology of this research will rely on a methodology that involves quantitative data analysis. The first step involves reviewing different techniques to measure earned value management. These different techniques will be reviewed comprehensively in the literature part. A comparison between the different techniques will take place in order to differentiate between each of these techniques in addition to highlighting their major differences. These techniques will be applied on numerous construction projects in Egypt in order to evaluate their efficiency based on different factors such as project type, total price, project duration and deviations between planned and actual cost and time. Analysis of the accuracy of these techniques will take place to determine which of these techniques fits and give more accurate results. In order to define the accuracy of each method, a numerical analysis will be conducted as a quantitative approach. Finally, based on the findings of the analysis, a model will be established to estimate the forecasted finish date. Details of the research methodology are described in Chapter 3, in addition figure one below illustrates the sequence of the research methodology.

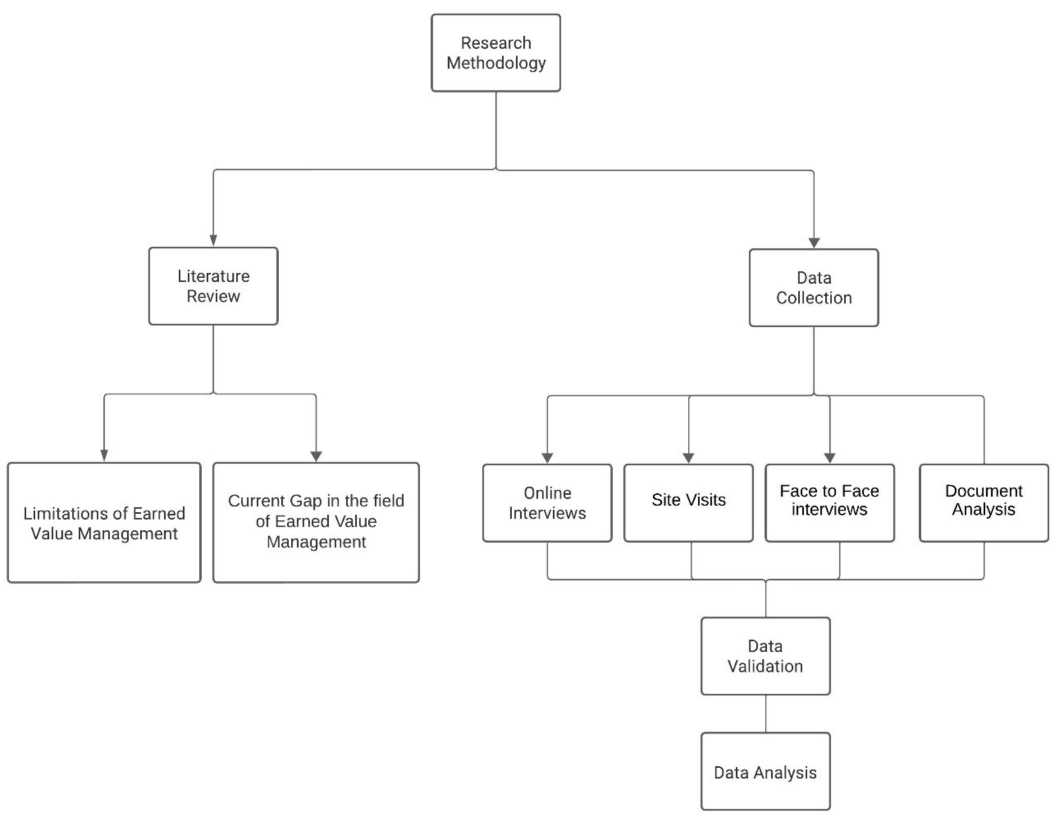

Figure 1 Research Methodology steps

1.5. Expected significance of the research

The research is anticipated to significantly contribute to the construction industry by enhancing project forecasting accuracy. The identification of the most effective earned value techniques for different project types and durations, as highlighted in the thesis, is expected to provide project managers with valuable insights to improve the precision of their forecasts.

The research's emphasis on tailoring the choice of earned value techniques to specific project characteristics is expected to be a valuable contribution. This tailored approach is anticipated to empower project managers to make informed decisions based on the unique requirements and dynamics of each construction project, fostering more efficient project management practices.

The practical guidelines introduced in the thesis for choosing the most efficient technique based on project duration percentages are expected to provide clarity in decision-making. Moreover, the research's nuanced understanding of the interplay of performance factors, including SPI and SCI, is anticipated to offer practical insights, enabling project managers to navigate complexities and optimize forecasting accuracy, with a special focus within the Egyptian market.

1.6. Thesis Organization

This document is organized into six chapters, each serving a distinct purpose in the exploration and analysis of EVM in construction projects.

Chapter 1 provides a comprehensive overview, starting with a general introduction to the research topic. It includes a clear statement of the problem, articulation of the research goals and objectives, an explanation of the chosen research methodology, and an overview of the expected significance of the study.

The second chapter is dedicated to the literature review, offering a thorough examination of background information on the subject, an exploration of various EVM methods, and a review of relevant previous studies. This chapter serves to establish the context for the current research and identify gaps in existing knowledge.

Chapter three details the research methodology employed in this study. It outlines the chosen data collection methods and elucidates the data analysis techniques applied to scrutinize the collected information. This chapter serves as a roadmap for the systematic execution of the research.

The fourth chapter delves into the specifics of data collection, providing detailed information about the projects selected for analysis. This section offers insights into the variables, parameters, and scope of the data collected for the study.

Chapter five is dedicated to the analysis of the collected data. It presents the outcomes of the analysis, providing a comprehensive understanding of the research findings.

The chapter six concludes with a summarization of the key insights and implications drawn from the analysis, marking the end of the research journey.

Chapter 2: Literature Review

2.1. Background

The failure of construction projects in meeting cost and schedule requirement has forced project managers to find any opportunity to invoke their learning and understand the causes of failure for future projects (Hughes et al, 2017). In an effort to enhance project management success rates, EVM has been developed as a tool that managers can utilize to aid in the attainment of desired client deliverables. EVM has been in existence for some time, and its effective implementation in projects remains a persistent challenge.

EVM is a project management technique used for improving the rate of success of construction projects (Aramali et al, 2022). EVM stands as the most extensive approach for overseeing and managing a project's cost and schedule performance by unifying the project's scope, budget, and timeframe (Dube, 2018). There are many other sectors that are using the methodology of EVM such as software industry, space industry, military applications, and energy sector, and this application still improving and developing widely. Company managers continually strive to minimize costs in the manufacturing and production processes, a task that significantly influences their financial management (Villafanez et al., 2020).

The history of EVM dates back to many decades ago and after the second world war. The critical path method (CPM) was introduced in the 1950s as a technique for assessing and enhancing performance. The US navy then invented the idea of using project evaluation review known as (PERT). PERT was established in a manner akin to CPM, and it served as a precursor to the development of EVM. After that, in 1960's the US government invented the idea of EVM to be used in their projects and measure their performance (Nevison and Chichakly, 2021). The establishment of the Project Management Institute in 1969 marked the initial significant milestone in the evolution of project management into a recognized profession (Kabeyi, 2019). The inception of project management functions enabled managers to discover practical solutions to project limitations.

EVM does not exclusively concentrate on the critical tasks of the project. It can involve all types of tasks (i.e., non-critical tasks, and critical tasks), whilst the critical path of the project is still considered essential to estimate the total time required to complete the project. The critical path comprises a continuous sequence of activities with no slack, and these activities are referred to as critical tasks. This indicates that controlling and monitoring the schedule of work in the project can concentrate on these main tasks as no delay can be allowed because any delay in these critical tasks can lead to the overall project delay (Corovic, 2022). Many tasks are allowed to finish late during the execution of the project. Nonetheless, the traditional earned value method would fail to detect these delays, and the schedule management indicators would indicate an ideal value even following the postponed task (Schedule performance index of one, or schedule variance of), which might not be the case (Corovic, 2022). EVM is helpful in accurately estimating savings and cost overruns in the execution of construction projects. Nevertheless, employing this approach for overseeing and managing schedule deviations is insufficient.

The utilization of EVM across all project levels enhances the likelihood of success by granting project managers the flexibility to make necessary adjustments for achieving success. EVM can be a short-term method that helps the project manager to measure and control the performance of the project after the inception stage and report anything related to the time and cost of the project (Mogaji, 2019). Earned Value Management Systems (EVMS) equip the project management team with software, procedures, instruments, and project templates to enhance project success rates. EVMS is an EVMS that aligns with the EIA-748 EVMS guidelines.

EVM tries to combine three correlated element of project performance, these are the cost, schedule, and scope (Geneste, 2019). The assessment method known as earned value analysis (EVA) empowers the project manager to employ a quantitative approach to gain a deeper insight into project performance. This is achieved by calculating schedule and cost variances throughout the project's duration. When the project manager finishes around 20% of the project, the rest of the performance may result in an estimation of around 10% plus or minus any variation. Project managers can utilize the information provided by EVM for trend analysis and forecasting, making it a valuable tool for cost control measures. With its robust predictive capabilities, EVM offers project managers an effective approach to project management.

Project managers can gain many benefits and advantages of utilizing EVM in their project management methods and to be used for measuring and evaluating the performance of their projects. EVM can provide stakeholders with transparent metrics, visibility, and clearly defined accountability. This technique can be excellent for managers in offering an unobstructed understanding of the project with an overall view of its performance starting from the inception stage and can still be effective and efficient with many project stages and at all levels. The procedure enables the project manager to take action proactively, making adjustments to the project scope and budgets, seeking additional resources, and managing customer expectations, all before a crisis arises. A database can be developed by project managers to help in taking many actions and assist in various aspects in the project including proper decision making for projects in the future and align their progress and work with unknown risks to be reduced in future projects and ensure the prevention of any cost overrun especially from risks that were considered critical in the past and had severe impact. Furthermore, and of utmost significance, managers can employ the tool to conduct a comparison and establish benchmarks for the current project status when compared to the project's initial baseline. Additionally, they can pinpoint the critical path. Mogaji (2019) indicated that a basic technique of EVM in a construction project can help project managers with an adequate and accurate estimation and forecasting of around 20% of completed works in the project. There are many quantitative equations and formulas that are currently available to improve the performance of construction projects.

2.3. Earned Value Management

The traditional approach of managing changes in the project involves comparing the gap between the actual variable value and the planned value. As an illustration, it is possible to analyze the real accumulated project costs in comparison to the initial projected project costs to identify variances in the project's expenditure (Buestan et al, 2018). Nonetheless, this examination is partial because it's possible to have expended 90% of the budget while only completing 50% of the project. The traditional cost analysis techniques do not determine the status of the project and whether it is being performed properly, since the information about the execution of the project is not available (Buestan et al, 2018).

In the traditional approach, a couple of variables are compared with each other; the budgeted cost of the planned activities, known as the planned value (PV), and the actual real cost of the performed activities known as (AC) (Aramali et al, 2021). The planned value (PV) is linked to and symbolizes the project schedule in monetary terms, while the actual value (AC) is tied to the actual cost of the project in monetary units. This comparison neglects completely the scope of work which can be the third variable in the equation and a major constraint in construction projects (Aramali et al, 2021). This is accomplished by means of the earned value (EV) or the cost of work performed as budgeted, both of which are related to the project's scope variable in terms of monetary units (Aramali et al, 2021).

The concept of earned value is generated from the idea that every delivered project has a budgeted cost known as the value. When the cost of the project is well delivered, it indicates that the value is well earned. EVM integrates the three pertinent project baseline factors: scope, timetable, and financial plan (Zahoor et al, 2022). It is important to calculate many factors such as the earned value correlated with the scope of work in monetary units, the planned value correlated with schedule of work in monetary units, and lastly the actual cost of work in the project again in monetary units (Zahoor et al, 2022).

The budget cost at completion indicates the baseline cost for the project and the initial budget required in order to plan the performed work on site. It can be represented on the S curve of the project accumulating the expected cost of each task during the whole life cycle of the project. It signifies the anticipated value of all tasks and activities that are scheduled to be finished (Mayo-Alvarez et al, 2022). The budget cost at completion (BAC) can be calculated through the planned value as shown in equation 1:

$$PV = BAC * PW$$

Equation 1 planned value (Mayo-Alvarez et al, 2022).

Where:

- PV: Planned value
- BAC: budget cost at completion
- PW: planned work percentage

The other major variable in the EVM is the earned value (EV), which refers to the budgeted cost for the performed work It represents the projected cost, based on the budget, to complete the work that has been executed within the specified timeframe, rather than the actual cost. It helps in understanding the work performed until a specific date and the budgeted value, it can be calculated through equation two.

$$EV = BAC \times WD$$

Equation 2 Earned Value (Mayo-Alvarez et al, 2022).

Where:

- EV: Earned value
- BAC: budget cost at completion
- WD: work done percentage.

The actual cost is the incurred budget that was used for the performed work until a certain date (Mayo-Alvarez et al, 2022). This is the real-time cost of the work, encompassing both direct and indirect expenses. It provides insight into the total cost incurred for the work completed thus far. Its value is calculated as the sum of (quantities completed multiplied by the actual purchase price) (Mayo-Alvarez et al, 2022).

EVM is very valuable when used to compare the cost gaps of the project using cost performance index and cost variance indicators. These indicators can demonstrate if the project is suffering from cost overrun or achieving cost savings. The standard variance can be used to estimate the measurement of deviations in the schedule of work in the project and help in indicating the delay or project overruns (PMI, 2011). Figure 1 depicts the three curves related to PV (Planned Value), EV (Earned Value), and AC (Actual Cost), along with the cost and schedule variances measured in monetary units. Employing this method to monitor project schedule deviations may not effectively handle various project scenarios and does not utilize time units to report project progress or delays (PMI, 2011).

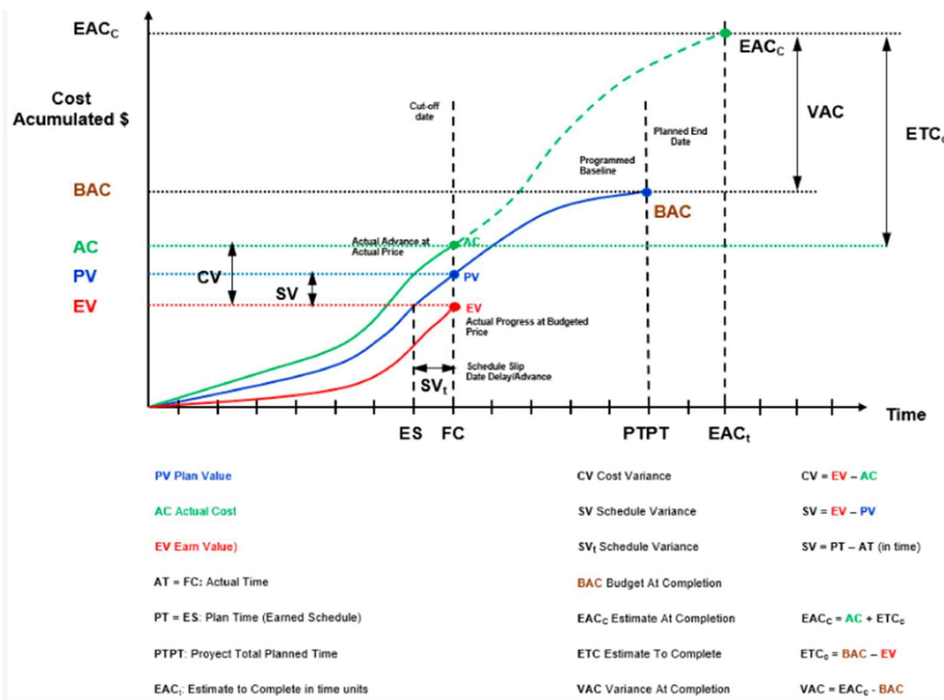

Figure 2: Earned Value Management: The three curves and cost and schedule variations (Mayo-Alvarez et al, 2022)

2.3.1. Earned Schedule

The earned schedule is basically the actual progress of work in the project valued or represented in time units (Lipke, 2012). The commonality between earned schedule and earned value is that they both utilize actual progress as their initial reference point (Kapuganti et al, 2019). The major variation between them lies in how expressing and showing the actual progress on site. Nevertheless, earned programming demonstrates the actual progress of work in the project in time unites, while the earned value demonstrates the actual progress in monetary figures (Henderson, 2005). The earned schedule method produces metrics that accurately gauge the project schedule's status throughout its entire life cycle. This approach enables the assessment of project progress or delays in terms of "time" units and effectively identifies and quantifies delays in activities that have been completed behind schedule (Henderson, 2005). Therefore, earned schedule helps to reduce two major limitations faced when using EVM as a method of project control (Henderson, 2005). The next figure indicates the earned schedule basic definition, where the earned schedule value is accomplished when the earned value on the control date is the same as the planned value in 9 months.

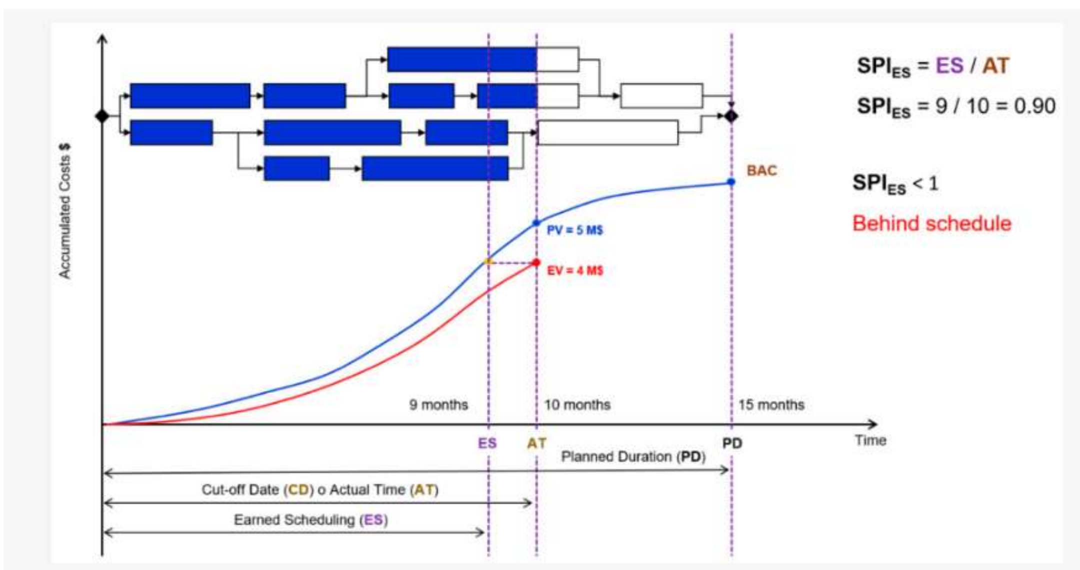

Figure 3: Basic illustration of the idea of earned schedule (Mayo-Alvarez et al, 2022)

The earned schedule is similar to the EVM in the case of plotting S curve as a representation and a reference for the schedule variation, but it does not differentiate between the non-critical activities and the critical ones (Capone and Narbaev, 2021). This particular aspect renders the accuracy of schedule variance measurement questionable because it suggests that only critical path tasks should be taken into account when overseeing the project's timeline

(Capone and Narbaev, 2021). Therefore, the critical path earned scheduling (ESRC) was developed to integrate the idea of earned schedule and critical path of the project and overcome the limitation of the original concept. To achieve this, it is essential to establish and utilize the S curve specifically for critical tasks as a benchmark to estimate schedule deviations (Capone and Narbaev, 2021).

2.4. Previous Studies

Bhosekar and Vyas (2012) studied the cost control of construction projects using EVM. The study concentrated more on the real estate sector. The study delved into the significance of the EVM tool, explored its fundamental formula along with performance indicators, and applied it to a case study involving a residential building covering an area of 120 square meters. This case study was used to conduct EVM analysis, tracking both time and cost indicators. To compare EVM analysis with software like MSP, P6, and SQL, the author compared multiple project management tools. Additionally, the paper concludes with a comparative analysis of EVM Analysis in contrast to various other management tools.

Virle et al (2013) discussed the implementation of both EVM and Earned Schedule (ES) in construction projects. In this study, the researcher explored the utilization of EVM in the construction sector, discussed the elements of EVM, and outlined the various parameters impacting the significance of ES and EVM.

Gaddam and Landage (2022) reviewed the utilization of earned schedule and EVM for construction projects. Project success is heavily reliant on achieving the anticipated cost and time of construction projects. Public and private sectors have a long history regarding the inability of completing projects on time and cost. Earned schedule and value management are two methodologies used in project management for organizing and monitoring the progress of work in the project. These methods are extremely useful in comparing the actual cost of work and the budgeted one while considering the analysis of schedule delays. EVM is quite efficient method for controlling and evaluating construction projects. It can be used by stakeholders, project managers, and most parties to visualize the progress of the project during its entire life cycle and allow the team to properly manage the project. On the other hand, earned schedule is more about the practical knowledge that builds the idea of EVM. It is now considered the newer extension to the concept of EVM. To enhance the control and evaluation of schedule of work and performance during the life cycle of the project, earned schedule allows EVM to convert its outcomes into time metrices. Project manger's performance can be comprehensively improved with earned schedule by forecasting and making better decisions in the project. The aim of this research was to apply the concepts of earned schedule management and EVM to a flyover infrastructure construction project in India to evaluate cost overrun and time delay. The results were then compared with the outcomes of using MSP software predictions. Study's findings demonstrated the ability to use ES and EVM to monitor and control the time and cost of infrastructure projects efficiently and accurately. It can aid in predicting early warning of variances in the time and cost using ESM and EVM parameters during the whole life cycle of the project.

Suresh and Ganapathy (2015) showed a study regarding the implementation of earned value analysis for evaluating project performance. The study addressed earned value analysis for examining the performance of construction projects. EVM offers the ability to understand the cost of construction projects and the impact of the performance, risks, and scope of work on the cost of projects. It motivates the management team to maintain a keen focus on cost, time, and progress, thereby facilitating smoother project execution. On the other hand, Chavan and Bhamre (2015) studied the ability to efficiently plan and schedule residential projects while conducting a delay analysis. The research focused on many aspects including manpower organizing, project planning, manpower management, project scheduling, project scheduling steps, delay analysis, manpower planning, introduction to scheduling, planning steps, introduction to planning, and other related information. Furthermore, a case study of a residential unit project was illustrated through the use of MS Project and MS Excel software. The study concluded with main points regarding the master schedule, planning of activities, and other topics. The main causes of delay in the project were weather conditions, lack of skilled labours, improper planning, poor organization, shortage of materials, and shortage of labours. Therefore, this study indicated the importance of proper planning for the success of construction projects and avoiding any time spent waiting.

Yvas (2016) tracked the progress of construction projects using EVM. The goal evolved around demonstrating the efficiency and role of EVM for project tracking and its superiority over the traditional approaches. EVM can be crucial for cost and delay analysis of construction projects as proven in this study and agreed by many studies in the literature. Hence, it concluded with the main benefits of using EVM in the construction industry and project management.

Mayo-Alvarez et al (2022) conducted an AHP systematic analysis of EVM techniques that are used to control and monitor the performance of construction projects. Successful management of projects relies on accomplishing the expected objectives. In these goals, technical achievement is linked to meeting the project's baseline expectations. The project's baseline defines lots of information about the project such as the total cost on the S curve, time of activities, and the work breakdown structure. In simple terms, the project is considered technically successful when it can deliver its entire scope according to the established schedule and without incurring additional costs. The baseline performance management helps project managers to control and monitor the process of activities, costs, durations, and deliverables in the project. In a conventional method, for projects following a waterfall approach and utilizing the critical path concept, the primary tool for managing baseline performance effectively is EVM (EVM). In practice, EVM is well effective for controlling the cost of construction projects, nevertheless, implementing this technique to estimate the schedule status is usually inconsistent and not effective. During the past few decades, various changes of the original concept of EVM have been introduced to overcome this inconsistency when it is applied to determine and measure the status of project's schedule and timeline. There are many variations under the original concept of EVM such as critical path earned schedule, critical path earned value, the earned schedule, the work in progress earned value, and the critical path earned value and the work progress combined. Every one of these suggestions aims to rectify certain shortcomings in the conventional approach of EVM when it comes to time tracking and control. For instance, they emphasize the importance of focusing on critical tasks for monitoring schedule progress, addressing the issue of delayed task recognition, reporting schedule variances in terms of time units, and measuring compliance with the project's schedule (referred to as the "P factor"). Given the challenging circumstances, it's imperative to identify the most suitable alternative from various versions of the original earned value method for effective project schedule management. This selection process involves considering multiple evaluation criteria. In this research, we conduct a systematic review and comparison of EVM (EVM) and its variants as tools for assessing project baseline schedule performance. To determine the most appropriate methods for schedule monitoring and control, we employ the Analytic Hierarchy Process (AHP) and evaluate five key criteria: focus on schedule variation in critical tasks, the ability to recognize and measure task delays, reporting schedule variances in time units, measuring schedule adherence (P factor), and the presence of software support and development. The outcome of the AHP analysis, when comparing these methods, reveals that the critical path earned schedule method is the most effective for monitoring and controlling project baseline schedules. It consistently performs well across all evaluated categories when compared to other methods.

Araszkiewicz and Bochenek (2019) presented a study about the use of earned value method for controlling construction projects through a case study. Effective execution of construction projects relies on essential management functions, which include planning, control, and progress monitoring. Scheduling and budgeting in the form of cost estimation are two functions and instruments that are used to control the performance of construction projects. These are established during the initial planning phase to oversee and manage deviations in both cost and time. Furthermore, common monitoring methods include milestone observation and comparative analysis of actual costs against the planned costs. This study presented the use of EVM as a progress control method to demonstrate its usage in the construction industry and its major benefits although its not commonly used by many projects. The study examines how the outcomes achieved during the monitoring and control phase are influenced by the planning phase when employing EVM. This case study offers real-world illustrations of EVM application in construction project execution, including the utilization of computer software. The novelty of the study was about introducing an extra sensitivity analysis showing the influence of other factors such as delay in delivery of materials or increase in projects costs while illustrating the impact on deviation curves. Employing sensitivity analysis in conjunction with the outcomes of CPI and SPI calculations allows for the integration of cost and time control with the monitoring of project risks. The results demonstrate notable advantages associated with the adoption of EVM for the execution of construction projects, while also underscoring certain noteworthy limitations.

Otuyemi (2017) discussed the potential use of EVM in the construction sector in the UK as a trend tool. In this paper, the application of EVM as an analytical instrument in the construction industry was examined. The primary goal was to demonstrate how EVM is implemented in previous projects and measure its influence on the success rate of construction projects. In this paper, we aimed to assess the utilization of this project management method through the examination of three case studies that demonstrate its practical implementation. These case studies are supported by reports, graphs, analyses, and commentary. EVM's role in contributing to the success of these case studies is evident through its ability to identify key issues and provide solutions that ultimately lead to on-time and on-budget project completion. In summary, the paper outlines how EVM has demonstrated its value to the construction sector by providing a clearer project perspective. It accomplishes this by presenting the project's status in terms of cost and time and by offering forecasts for project completion.

In conclusion, the studies presented provide valuable insights into the application and effectiveness of EVM in the construction industry and underscore the importance of EVM as a valuable tool for project management in the construction industry, offering insights into cost control, progress monitoring, and efficient decision-making.

The subsequent chapter is research methodology which will delve into the approaches, tools, and techniques employed to gather, analyze, and interpret data, providing a methodological framework to further enhance our understanding of the dynamics of EVM implementation in construction contexts. As we move forward, the research methodology chapter aims to bridge theoretical knowledge with practical application, contributing to a holistic comprehension of the role of EVM in optimizing project outcomes.

Chapter 3: Research Methodology

This chapter outlines design and approach used to answer all research questions and achieve the research objective. Selecting the right form of a methodology is extremely important to ensure the reliability, validity, and rigor of data collection and analysis to achieve all research objectives. The major goal of this chapter is to thoroughly present the methodological approach that helped the researcher in understanding the research methods of data collection and evaluation.

3.1. Research Design

There are many approaches that are used in scientific studies for data collection. The most commonly used ones are qualitative approach, quantitative approach, and mixed methods approach. Quantitative methods are used to gather statistical data that measures broad figures using numerical information. On the other hand, qualitative methods are more suitable in gathering the broad perspective of individuals and to be able to investigate deep thoughts and ideas which cannot be done through a survey. There are many studies that combine both qualitative and quantitative methods to form an approach known as mixed methods. Selecting the best design relies heavily on the context of the study, research aims and objectives, and the questions that are expected to be answered in the study. This study considered the adoption of a quantitative approach. This approach was selected due to its ability to comprehensively collect and analyse the required data for the context and phenomenon of this research. The quantitative aspects are useful for providing a broad understanding and perspective, which is different than the qualitative approach that only considers the theoretical explanation of complex contexts that requires deeper understanding of the problem. The goal of the study seeks to offer a holistic and nuanced viewpoint of the context that is being investigated in this research. EVM can be applied in many ways in the project and this study aimed at exploring the various methods under EVM which can be used in the scheduling of construction projects.

3.2. Data Collection Methodology

There are multiple techniques and methods that can be used by researchers in order to collect the required data for the research. All the data in this research was gathered using a range of multiple methods, each one of them was precisely chosen to align with the questions proposed in this research. These common methods of data collection include document analysis, literature review, descriptive analysis, questionnaire surveys, and in-depth interviews with respondents. The decision to choose a certain technique was mainly based on the research context, research questions, and the objectives that are expected to be accomplished at the end.

The literature review aided in obtaining the equations that can be used to apply the various types and methods of EVM. The other method of data collection was document analysis which involved many previous construction projects. The process of document analysis was concerned mainly with evaluating the descriptive information of previous construction projects to obtain any data regarding the time and cost of each project. This data was vital for the following steps in this research including the ability to use EVM methods and equations and estimate the total duration of construction projects. The next parts of the methodology discussed the data analysis and the implementation of EVM techniques and equations.

Document analysis is used to offer previous insight and historical context, interviews are useful for exploring the perspective of individuals, while surveys are preferred to obtain quantitative data that is broad and from multiple perspectives. This study opted to use quantitative methods to analyse the implementation of EVM techniques in the construction sector and use many equations that can estimate the time and schedule of work in the project. The initial method of data collection that was used in this study was a literature review. This method helped in gathering extensive data and information about the concept of EVM and its application in the construction sector. Following the methods used for data collection.

3.2.1 Online Interviews:

Online interviews were conducted with relevant stakeholders, including project managers, contractors, cost engineers and planning engineers. These interviews helped in obtaining valuable insights into the project details, including planned schedules, budgets, and actual performance data.

3.2.2 Site Visits:

Site visits were an integral part of the data collection process. They provided an opportunity to observe the progress of the projects firsthand, collect visual evidence, and verify the accuracy of the information provided during online interviews.

3.2.3 Face-to-Face Interviews:

Face-to-face interviews with project team members and site personnel allowed to gather more specific details about the projects, such as any unexpected challenges faced during construction and deviations from the original plans.

3.2.4 Document Analysis:

Various project documents were analyzed to extract critical data. These documents included baseline schedules, monthly cost reports, and monthly progress updates. The analysis of these documents provided comprehensive information about project timelines, budgets, and performance metrics.

3.3 Data Source

The data for this analysis was collected from well-known contractors in Egypt who had executed these projects. The projects were distributed across multiple cities, including Cairo, Ain Sokhna, Alexandria, North Coast, Gouna, Giza, and 6th of October. This geographic diversity allowed us to examine construction projects within the same country, taking into account regional variations and challenges.

3.4 Data Collection Tools

To collect and analyze project data, the following tools were utilized:

3.4.1 Primavera P6:

Primavera P6, a widely used project management software, was employed to access and extract schedule-related data. This tool facilitated the gathering of information on planned start and finish dates, as well as progress over time.

3.4.2 Microsoft Excel:

Microsoft Excel was utilized to manage and analyze cost data. It allowed for the comparison of planned and actual project costs, enabling us to identify budget overruns or savings.

3.4.3 Power Point Presentations:

Weekly progress presentations were utilized to manage the progress data, which allow to compare between the budget cost of work schedule and the project cost of work performed.

3.5 Data Validation

To ensure the reliability and accuracy of the collected data, several measures were taken:

3.5.1 Multiple Interviews:

Multiple interviews were conducted with different sources, including contractors, project managers, and site personnel, to cross-verify the information provided and minimize potential biases.

3.5.2 Site Visits:

Site visits played a crucial role in verifying the data. On-site observations and data collection helped in confirming the progress and performance of the projects.

3.6 Data Collection Duration

The data collection process spanned approximately one year. This duration was necessary to obtain comprehensive and accurate information for all 30 selected projects. Some of the data collection tasks, such as site visits, required substantial time and effort.

3.7. Data Analysis Methodology

The gathered data from the document analysis was then evaluated and used to apply the idea of EVM. All of the collected data was thoroughly analysed using a pre-defined process. After obtaining the earned value (EV), planned value (PV), and actual cost (AC) data for each project, the calculations for three different techniques will be discussed separately. The subsequent table summarizes the distinctions between these three methods and the calculations involved in forecasting the project's completion date.

Earned Schedule Method			Earned Duration Method			Planned Value Method		
Metric	**Defination**	**Formula**	**Metric**	**Defination**	**Formula**	**Metric**	**Defination**	**Formula**
Earned Schedule = ES	Earned schedule is the amount of time the project desereve as per the project progress.	$ES = \mathrm{t} + \frac{\mathrm{EV} - PV_t}{PV_{t+1} - PV_t}$	Earned Duration = ED	the amount of duration the project deserves based on the project progress	AD X SPI	Pv rate = Planned Value rate	the planned rate per time in order to finish the project on time where BAC = budget at completion and PD is the planned project duration.	$PV_r = \frac{BAC}{PD}$
EAC at PF = 1	is the Estimate at completion is the forecast of project duration when PF = 1	$EAC_t = AT + \mathrm{PDWR}$	SPI = Schedule Performance Index	Indicate the difference between the budget cost of work performed and the budget cost of work	$\mathrm{SPI} = \frac{EV}{PV}$	TV = Time Variance	the difference in time between the planned budget and actual cost in time units and it is calculated	$TV = \frac{SV}{PV_r}$
SPI(t)	Schedule performance index in time units	$\mathrm{SPI(t)} = \frac{ES}{AT}$	SCI	Schedule cost index indicates the progress performance based on time and cost	SCI = SPI X CPI	SPI = Schedule Performance Index	indicate the difference between the budget cost of work performed and the budget cost of work performed according to the schedule in pecentage	$\mathrm{SPI} = \frac{EV}{PV}$
SCI	Schedule cost index indicates the progress performance based on time and cost	SCI = SPI X CPI	EAC at PF = 1	is the Estimate at completion is the forecast of project duration when PF = 1	$\mathrm{UDR} = PD - ED$	SCI	Schedule cost index indicates the progress performance based on time and cost	SCI = SPI X CPI
SCI(t)	Schedule cost index in time units	SCI(t) = SPI(t) X SCI	EAC at PF = SPI	is the Estimate at completion is the forecast of project duration when PF = SPI	$\mathrm{EDAC} = \mathrm{AD} + \frac{\mathrm{PD-ED}}{SPI}$	TEAC at PF = 1	Time estimate at completion is the forecast of the project duration when the performance factor is equal to 1 when the remaining work is as planned	TEAC = PD – TV
EAC at PF = SPI(t)	is the Estimate at completion is the forecast of project duration when PF = SPI	$EAC_t = AT + \frac{\mathrm{PDWR}}{SPI}$	EAC at PF = SCI	is the Estimate at completion is the forecast of project duration when PF = SCI	$\mathrm{EDAC} = \mathrm{AD} + \frac{\mathrm{PD-ED}}{SCI}$	TEAC at PF = SPI	Time estimate at completion is the forecast of the project duration when the performance factor is equal to 1 when the remaining work is following SPI	$TEAC = \frac{PD}{SPI}$
EAC at PF = SCI	is the Estimate at completion is the forecast of project duration when PF = SCI	$EAC_t = AT + \frac{\mathrm{PDWR}}{SCI}$	Accuracy	the Accuracy of estimating the forecast finish date	$\mathrm{Accuracy} = \frac{\lvert \mathrm{AD} - EAC_t \rvert}{AD}$	TEAC at PF = SCI	Time estimate at completion is the forecast of the project duration when the performance factor is equal to 1 when the remaining work is following SPI and CPI	$TEAC = \frac{PD}{SCI}$
Accuracy	the Accuracy of estimating the forecast finish date	$\mathrm{Accuracy} = \frac{\lvert \mathrm{AD} - EAC_t \rvert}{AD}$				Accuracy	the Accuracy of estimating the forecast finish date	$\mathrm{Accuracy} = \frac{\lvert \mathrm{AD} - EAC_t \rvert}{AD}$

Table 1 Comparison between three methods

1- The Earned Schedule method relies on the concept of earned schedule, which is calculated as follows:

$$ES = \mathrm{t} + \frac{\mathrm{EV} - PV_t}{PV_{t+1} - PV_t}$$

Equation 3 Earned Schedule (Vanhoucke,2009)

Where ES = Earned schedule

t = Time where earned value happened

PV_t= = Planned value at time t

PV_{t+1}= Planned value at time t+1

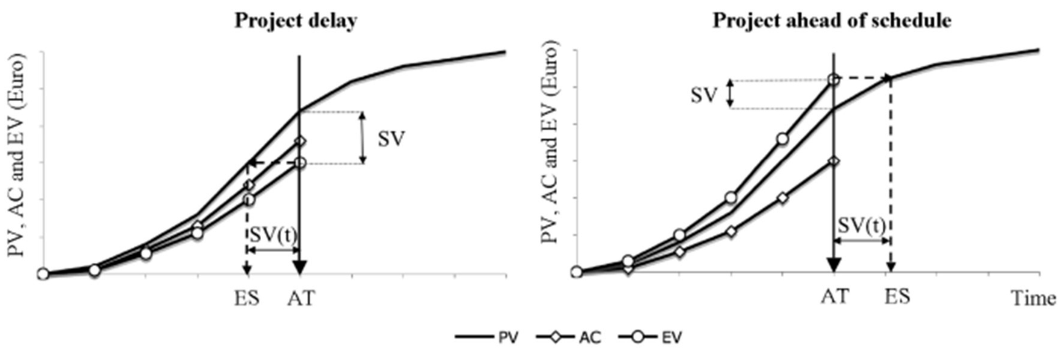

Figure 4: ES difference between two scenarios

The graphical presentation above shows the difference between earned schedule when the project is ahead of schedule as shown in the right and in case of the project is delayed as shown in the figure on the left.

Where SV(t) is the schedule variance in time units and SV is schedule variance in cost units, and AT is the actual time.

To calculate the Estimate at completion in time units the equation is as follows:

$$EAC_t = AT + \frac{\mathrm{PDWR}}{PF}$$

Equation 4 Estimate at Completion (Vanhoucke,2009)

Where AT is the actual time and PDWR is the planned duration for work remaining and PF is the performance factor where PF = 1 when the duration of the remaining work is as planned and PF = SPI(t) when the duration of remaining work is following the SPI(t) trend and PF = SCI(t) when duration of remaining work is following the cost and time trend.

The calculation of SPI, SPI(t), SCI, SCI(t) is as follows:

$$\mathrm{SPI} = \frac{EV}{PV}$$

$$\mathrm{SPI(t)} = \frac{ES}{AT}$$

Equation 5 Schedule Performance index (Vanhoucke,2009)

$$SCI = SPI \text{ X } CPI$$

$$SCI(t) = SPI(t) \text{ X } SCI$$

Equation 6 Schedule Cost Index (Vanhoucke,2009)

Finally, PDWR = PD – AT

Where PD is the planned duration and AT is the actual duration.

In order to examine the accuracy of the estimation the following equation is used:

$$\text{Accuracy} = \frac{|\text{AD} - EA\ \ t|}{AD}$$

Equation 7 Accuracy (Vanhoucke,2009)

Where AD is the equal to the actual project finish date, and the EAC is the estimation at completion.

2- Earned Duration Method uses the concept of earned duration and it is calculated using the following formula:

$$\text{ED Earned Duration} = \text{AD X SPI}$$

Equation 8 Earned Duration (Vanhoucke,2009)

Where AD is the Actual duration and SPI is the schedule performance index and it is calculated as before.

The Estimate at completion in time units using this method is called estimate duration at completion (EDAC) and it is calculated as follows:

$$EDAC = AD + UDR$$

Equation 9 Estimate Duration at Completion (Vanhoucke,2009)

Where UDR is unearned duration remaining and AD is the actual duration.

UDR is calculated using the following formula where PD is the planned duration, ED is the earned duration and PF is the performance factor.

$$\text{UDR} = \frac{\text{PD} - \text{ED}}{PF}$$

Equation 10 Unearned Duration Remaining (Vanhoucke,2009)

Similar to the previous method performance factor could be PF = 1, SPI, SCI based on the calculations of the remaining duration.

After that assess the accuracy of the estimation the following equation is used:

$$\text{Accuracy} = \frac{|\text{AD}- \quad t|}{AD}$$

Where EDAC is the estimate duration at completion and AD is the actual duration of the project.

3- The third and final method is the planned value method which is calculated based on a metric called planned value rate PV_r and TV which the time variance.

$$PV_r = \frac{BAC}{PD}$$

Equation 11 Planned Value rate (Vanhoucke,2009)

PV_r is the planned rate per time to finish the project on time where BAC = budget at completion and PD is the planned project duration.

As for the time variance (TV) is the difference in time between the planned budget and actual cost in time units and it is calculated using the following equation:

$$TV = \frac{SV}{PV_r}$$

Equation 12 Time Variance (Vanhoucke,2009)

Where SV is the schedule variance, and it is calculated as follows SV = EV – PV

With the PV_r the time variance is calculated.

The calculation of the estimate at completion is calculated using TEAC which is time estimate at completion and it is calculated using this formula TEAC = PD – TV when the remaining work is following the plan, when the remaining work is following the SPI trend, this formula is used

$$TEAC = \frac{PD}{SPI}$$

Equation 13 Time Estimate At Completion (Vanhoucke,2009)

Finally, when the remaining work is following the SCI trend the following formula is used.

$$TEAC = \frac{PD}{SCI}$$

Similarly, the accuracy is of the estimation is calculated using the following equation:

$$\text{Accuracy} = \frac{|\text{AD} - \text{TEAC}|}{AD}$$

3.8. Ethical Considerations

To maintain confidentiality and ethical standards, the names of the contractors and specific project details were excluded from this research. Instead, projects were categorized by type, such as commercial, educational, power stations, renovation, administrative, and residential.

Chapter 4: Data Collection

In this chapter, we provide an overview of the data collection process for the analysis of 30 construction projects across various cities in Egypt. These projects were selected from different sectors, including commercial, educational, power stations, renovation, administrative, and residential projects. The data collection process involved a combination of methods, tools, and sources to gather relevant information for our analysis.

4.6 Projects Overview

The outcomes derived from site visits and interviews include the collection of BCWP, ACWP, and BCWS data from 30 projects.

1. Budgeted Cost of Work Performed (BCWP): BCWP, also known as EV, represents the value of the work that has actually been completed in monetary terms. This metric reflects the progress made in a project and is measured on a monthly basis to track how much of the planned work has been accomplished.

2. Budgeted Cost of Work Scheduled (BCWS): BCWS, also referred to as PV, signifies the budgeted value of the work that was originally scheduled to be completed during a specific period. It provides a planned baseline for project performance and is assessed monthly to compare the planned progress with the actual progress.

3. Actual Cost of Work Performed (ACWP): ACWP represents the actual costs incurred during a given month in executing the project. This metric is essential for monitoring project expenses and determining the financial aspects of project execution.

Additionally, both the original schedules and actual schedules were gathered to facilitate the analysis of the collected data. The detailed presentation of the data collected for each project will be provided below. The projects used will be discussed in briefly in the table below and in details.

Table 2 Projects Data collected.

Project	Type	BCWS (EGP)	BCWP (EGP)	ACWP (EGP)	CV (EGP)	Planned finish	Actual finish	Deviation (Days)
1	commercial	160,387,330	160,387,330	171,886,590	-11,499,260	20-Feb-18	30-Oct-18	-252
2	Educational	145,263,973	145,263,973	157,985,453	-12,721,480	30-Apr-17	20-Dec-17	-234
3	Industrial	322,179,850	322,179,850	334,650,146	-12,470,296	19-Apr-19	30-Sep-19	-164

4	commercial	498,371,317	498,371,317	510,650,568	-12,279,251	4-Sep-19	30-Nov-20	-453
5	Residential	1,844,515,667	1,328,283,068	1,297,649,614	30,633,454	13-Jan-23	30-Jun-23	-169
6	commercial	505,782,177	505,782,177	455,858,281	49,923,896	30-Mar-21	30-May-21	-61
7	Renovation	129,946,203	129,946,203	149,674,697	-19,728,494	30-Sep-21	30-Dec-21	-91
8	Educational	524,011,456	524,011,456	491,657,287	32,354,169	25-Sep-20	20-Nov-20	-56
9	Residential	934,084,850	869,551,166	908,852,210	-39,301,044	25-Oct-21	28-Feb-23	-491
10	commercial	101,460,922	101,460,922	103,647,402	-2,186,480	20-Mar-16	28-Feb-17	-345
11	commercial	278,072,672	278,072,672	276,227,816	1,844,856	7-Dec-21	30-Nov-22	-358
12	commercial	224,382,775	224,382,775	231,577,203	-7,194,428	1-Oct-19	31-Mar-20	-182
13	Industrial	391,381,394	391,381,394	345,945,404	45,435,990	21-Feb-17	30-Dec-17	-312
14	Educational	237,039,879	237,039,879	228,301,480	8,738,399	20-Jul-19	14-Sep-19	-56
15	commercial	106,717,901	106,717,901	99,209,499	7,508,402	31-Dec-20	25-Jan-21	-25
16	commercial	209,859,079	209,859,079	237,328,844	-27,469,765	17-Nov-22	30-Jun-23	-225
17	Educational	583,273,944	583,273,944	677,666,732	-94,392,788	17-Apr-23	30-Oct-23	-196
18	commercial	550,151,073	489,264,996	553,748,233	-64,483,237	4-Aug-22	30-Mar-23	-239
19	Industrial	154,528,736	154,528,736	136,354,130	18,174,606	20-Jun-20	29-Jul-21	-404
20	commercial	758,418,631	758,418,631	628,632,758	129,785,873	31-May-22	30-Mar-23	-303
21	Residential	39,050,912	39,050,912	38,163,075	887,837	22-Apr-20	30-Jun-20	-69
22	Industrial	1,540,046,857	1,540,046,857	1,253,676,323	286,370,534	12-May-20	30-Sep-21	-506
23	Industrial	188,803,564	188,803,564	200,787,624	-11,984,060	3-Apr-21	15-Jun-21	-73
24	commercial	61,742,362	61,742,362	57,837,539	3,904,823	30-Jan-19	30-Apr-19	-90
25	commercial	341,780,342	341,780,342	360,220,926	-18,440,584	23-Jan-23	30-Dec-23	-341
26	commercial	74,027,664	74,027,664	80,492,656	-6,464,992	26-May-22	30-Aug-23	-460
27	commercial	172,742,103	172,742,103	192,355,326	-19,613,223	2-Mar-20	30-Dec-20	-303
28	Residential	299,554,952	299,554,952	339,899,961	-40,345,009	24-Jul-17	30-Apr-18	-280
29	Industrial	167,766,090	167,766,090	160,622,767	7,143,323	31-Jan-19	30-Apr-19	-89
30	Industrial	106,927,735	106,927,735	95,321,477	11,606,258	15-Feb-17	30-Sep-17	-227

Project 1: Commercial Project

Project 1 commenced on March 1, 2015, with a planned completion date of February 20, 2018. However, it encountered delays, resulting in an actual finish date of October 30, 2018, which was 252 days behind schedule. The project had a planned budget of 160 million EGP, but the actual cost amounted to 172 million EGP, exceeding the budget by 12 million EGP. The Schedule Performance Index (SPI) started at 76% but dropped to 55%, indicating that the project was both over budget and behind schedule.

Project 2: Educational Project

This educational project began on July 25, 2015, with a scheduled completion date of April 30, 2017. Unfortunately, it faced delays and ultimately finished on December 20, 2017, 234 days later than planned. The planned budget was 145 million EGP, but the actual cost reached 157 million EGP, resulting in a 12 million EGP budget overrun. The SPI started at 92% but declined to 66%, indicating that the project was both over budget and behind schedule.

Project 3: Power Station Project

Project 3 was a power station project that was initially planned to start on November 5, 2017, and finish on April 19, 2019. However, it experienced delays and concluded on September 30, 2019, 164 days later than scheduled. The planned budget for the project was 322 million EGP, but the actual cost amounted to 335 million EGP, resulting in a 13 million EGP budget deviation. The SPI trend began at around 50% and improved to 87%, with an average SPI of approximately 80%. Nevertheless, the project was both over budget and behind schedule.

Project 4: Commercial Project

Project 4, a commercial project, was initiated on May 6, 2017, with a planned completion date of September 4, 2019. However, it faced scheduling challenges, resulting in an actual finish date of November 30, 2020, which was 453 days later than anticipated. The project was budgeted at 498 million EGP, and the actual cost reached 510 million EGP, exceeding the budget by 12 million EGP. The SPI trend showed fluctuations, starting on schedule, and dropping to 43%, and the CPI trend fluctuated between 88% and 95%. Consequently, the project was both over budget and behind schedule.

Project 5: Residential Project

This residential project was set to commence on January 14, 2021, with a planned finish date of January 13, 2023. Unfortunately, it experienced delays, and the forecasted finish date extended to March 31, 2023, resulting in a deviation of 78 days from the original schedule. The SPI trend began at 117% but dropped to 76%, indicating that the project was behind schedule. On the other hand, the CPI trend remained nearly constant at 105%, indicating that the project was under budget.

Project 6: Commercial Project

Project 6, another commercial project, was scheduled to begin on September 29, 2019, and conclude on March 30, 2021. However, it faced setbacks, and the actual finish occurred on May 30, 2021, with a 61-day deviation from the original plan. The planned budget for the project was 505 million EGP, but the actual cost was 455 million EGP, resulting in a budget surplus of nearly 50 million EGP. The CPI trend remained consistently at 111%, indicating that the project was under budget, although it was behind schedule.

Project 7: Renovation Project

A renovation project, Project 7, was slated to start on March 10, 2018, and finish on September 30, 2021. However, it experienced delays and was completed on December 30, 2021, with a 91-day deviation from the planned schedule. The planned budget for the project was 130 million EGP, but the actual cost reached 150 million EGP, resulting in a 20 million EGP budget overrun. The SPI trend started at 110% but decreased to 97%, and the CPI began at 130% and decreased to 87%. Consequently, the project was both over budget and behind schedule.

Project 8: Educational Project

Project 8, an educational project, was set to commence on September 25, 2019, and conclude on September 25, 2020. However, it faced scheduling challenges and was completed on November 20, 2020, 56 days later than planned. The planned budget for the project was 524 million EGP, while the actual cost was 492 million EGP, resulting in an underspend of 32 million EGP. The SPI trend started at 95% but fluctuated, while the CPI trend showed an average of 108%. Consequently, the project was under budget but behind schedule.

Project 9: Commercial Project

Project 9, also a commercial project, was planned to start on October 19, 2014, and finish on March 20, 2016. However, it experienced a significant drop in the SPI, reaching around 55%, and concluded on February 28, 2017, with an extra 345 days compared to the planned schedule. The planned budget was 101 million EGP, and the actual cost amounted to 103 million EGP, resulting in a 2 million EGP budget deviation. The CPI remained at around 96% throughout the project, indicating that the project was both behind schedule and over budget by 2 million EGP.

Project 10: Residential Project

Project 10, a residential project, was planned to start on September 28, 2020, and finish on October 25, 2021, with a total duration of 757 days. However, the SPI trend started at 85% and declined to 62%, and the project was forecasted to finish on February 28, 2023, with a deviation of 491 days from the original schedule. The planned budget was 934 million EGP, and the actual cost was 908 million EGP, resulting in an overspend of 26. The CPI trend started at 111% and dropped to 96%. Consequently, the project was behind schedule and over budget.

Project 11: Administrative Project

Project 11, an administrative project, was scheduled to start on December 8, 2020, and finish on December 7, 2021, with an overall duration of 364 days. However, the SPI trend started at 90% and dropped to 35%, resulting in the project finishing on November 30, 2022, with a deviation of 358 days from the original plan. The CPI trend began at 133% and decreased to 98%. Based on the CPI percentage, the project budget was 278 million EGP, and the actual cost was 276 million EGP, indicating that the project was under budget by 2 million EGP.

Project 12: Commercial Project

Project 12, another commercial project, was planned to start on May 10, 2018, and end on October 1, 2019. Unfortunately, it faced scheduling issues as the SPI dropped to 70%, resulting in the project concluding on March 31, 2020, with a deviation of 182 days from the schedule. The planned budget was 224 million EGP, and the actual cost was 231 million EGP, resulting in a budget deviation of 7 million EGP. The CPI trend fluctuated between 108% and 101%. Consequently, the project was behind schedule but within budget.

Project 13: Industrial Project

Project 13, an industrial project, was scheduled to start on December 1, 2015, and finish on February 21, 2017. However, the SPI dropped to 75%, leading to the project's completion on December 30, 2017, with a deviation of 312 days from the planned schedule. The project budget was not disclosed, but the cost performance index ranged from 102% to 114%, and the project concluded with a CPI of 113%. This indicated that the project was under budget but behind schedule.

Project 14: Educational Project

Project 14, an educational project, was planned to start on September 9, 2018, and end on July 20, 2019, with an initial duration of 314 days. However, the SPI dropped from 96% to 75%, resulting in the project's completion on September 14, 2019, with a deviation of 56 days. The cost performance index (CPI) began at 111% but dropped to 104%, indicating that the project was under budget but behind schedule.

Project 15: Commercial Project

Project 15 was a commercial project set to start on October 13, 2019, and finish on December 31, 2020. However, the SPI fluctuated between 105% and 95%, causing the project to be completed on January 25, 2021, with a 25-day delay. The planned budget for the project was not disclosed, but the CPI ranged from 127% to 108%, ending at 108%. The project was behind schedule but within budget.

Project 16: Commercial Project

Project 16, another commercial project, was planned to start on November 17, 2021, and end on November 17, 2022. However, the SPI dropped from 90% to 69%, resulting in the project's completion on June 30, 2023, with a deviation of 225 days. The planned budget for the project was not disclosed, but the CPI trend started at 111% and dropped to 88%. The project was both over budget and behind schedule.

Project 17: Commercial Project

Project 17, a commercial project, was scheduled to start on April 20, 2021, and finish on April 17, 2023. However, the SPI trend started at 105% and dropped to 72%, resulting in a completion date of October 30, 2023, with a 196-day deviation from the planned schedule. The planned budget for the project was 583 million EGP, but the actual cost reached 677 million EGP, resulting in a 94 million EGP budget overrun. The SPI trend indicated that the project was both over budget and behind schedule.

Project 18: Commercial Project

Project 18 was a commercial project planned to start on December 15, 2021, and finish on August 4, 2022. The expected actual finish date was March 30, 2023, with a deviation of 239 days. The planned budget for the project was 550 million EGP, the earned value was 489 million EGP, and the actual cost was 553 million EGP, indicating a budget deficit of 64 million EGP. The SPI was 80%, and the CPI was 88%, demonstrating that the project was behind schedule and over budget.

Project 19: Industrial Project

Project 19, an industrial project, was intended to start on December 20, 2018, and finish on June 20, 2020. However, it concluded on July 29, 2021, with a deviation of 89 days. The planned budget was 154 million EGP, and the actual cost was 136 million EGP, resulting in an underspend of 18 million EGP. The SPI was 49%, and the CPI was 113%, indicating that the project was behind schedule but under budget.

Project 20: Commercial Project

Project 20, another commercial project, was planned to start on January 22, 2020, and finish on May 31, 2022. However, the project was completed on March 30, 2023, with a 303-day delay. The planned budget was 758 million EGP, and the actual cost was 628 million EGP, resulting in an underspend of 130 million EGP. The SPI was 68%, and the CPI was 121%, demonstrating that the project was behind schedule but under budget.

Project 21: Residential Project

This residential project was scheduled to begin on August 22, 2019, and finish in 2020, but it concluded on June 30, 2020, with a 69-day deviation. No cost deviation information was provided.

Project 22: Industrial Project

Project 22 was an industrial project that was planned to start on November 12, 2018, and finish on May 12, 2020. However, it finished on September 30, 2021, with a deviation of 506 days from the planned duration. The planned budget was 1540 million EGP, but the actual cost was 1253 million EGP, indicating a budget deviation of 286 million EGP. The SPI was 66%, and the CPI was 123%, showing that the project was behind schedule and under budget.

Project 23: Industrial Project

Project 23 was an industrial project that was planned to start on May 3, 2020, and finish on April 3, 2021. However, it finished on June 15, 2021, with a delay of 73 days from the planned duration. The planned budget was 189 million EGP, but the actual cost was 201 million EGP, indicating a budget deviation of 12 million EGP. The SPI was 94%, and the CPI was 73%, showing that the project was behind schedule and over budget.

Certainly, here's a rephrased version of the information about Projects 24 to 30 in paragraph format:

Project 24: Commercial Project

Project 24 falls under the category of commercial projects. Originally scheduled to commence on June 1, 2018, and conclude by January 30, 2019, it faced a deviation, finishing on April 30, 2019, marking a 90-day delay. The Schedule Performance Index (SPI) at the planned duration was 54%. In terms of budget, it's important to note that the project consistently remained under budget throughout its duration, concluding with an actual cost of 58 million EGP compared to the planned budget of 62 million EGP, resulting in a 4 million EGP budget surplus.

Project 25: Commercial Project

Project 25 is another commercial project that was initially planned to kick off on August 15, 2021, and wrap up by January 23, 2023. Unfortunately, due to low performance, it concluded on December 30, 2023, reflecting a significant deviation of 341 days from the original plan, which was a 526-day schedule. The SPI at the planned duration was at 61%. In terms of costs, the Cost Performance Index (CPI) began under budget at 111% but progressively decreased to 95% by the project's end, resulting in a 19 million EGP deviation from the planned budget of 342 million EGP, with an actual cost of 360 million EGP.

Project 26: Commercial Project

Project 26, also classified as a commercial project, was initially intended to start on May 18, 2021, and conclude on May 26, 2022. However, it faced substantial delays, concluding on August 30, 2023, resulting in a total duration of 834 days instead of the planned 373 days. The SPI at the planned duration was 65%. On the cost front, the project initially operated under budget, but it gradually moved into an over-budget scenario, with a final CPI of 92%.

Project 27: Commercial Project

Project 27, another commercial project, was initially scheduled to begin on October 1, 2019, and end on March 2, 2020. However, the project faced significant delays, concluding on December 30, 2020, representing a total deviation of 303 days from the planned duration, which was initially set at 153 days. The SPI at the end of the project was 56%. In terms of costs, the project experienced a continuous state of being over budget, with a CPI of 95% at the start and 90% at the conclusion.

Project 28: Residential Project

Project 28 falls into the residential project category. It was planned to start on March 23, 2015, and finish by July 24, 2017. However, the project experienced a substantial delay, concluding on April 30, 2018, marking a total deviation of 280 days from the planned 854-day duration. The project consistently lagged behind schedule. On the cost side, it was over budget throughout its duration, with a 40 million EGP deviation from the planned budget of 300 million EGP, concluding with an actual cost of 340 million EGP.

Project 29: Industrial Project

Project 29 is an industrial project that was initially scheduled to begin on July 2, 2018, and conclude by December 31, 2019. However, the project finished on April 30, 2019, with an 89-day deviation from the planned duration, primarily due to low performance and a low SPI. From a cost perspective, the project remained under budget throughout, with a 7 million EGP budget surplus when compared to the planned budget of 167 million EGP and an actual cost of 160 million EGP.

Project 30: Industrial Project

Finally, Project 30, another industrial project, was planned to begin on June 5, 2016, and conclude by February 15, 2017, representing a total duration of 255 days. However, the project faced extensive delays, concluding on September 30, 2017, with an actual duration of 482 days, resulting in a 227-day deviation from the planned finish date. The project was behind schedule primarily due to low performance, with an SPI of 50% at the planned finish date. In terms of costs, the project consistently remained under budget, concluding with an actual cost of 95 million EGP compared to the planned budget of 107 million EGP, resulting in an 11 million EGP budget surplus.

4.7 Conclusion

In this Chapter, the data collection process, and an overview of the 30 projects analyzed for this study. The projects were collected from various cities across Egypt, including Cairo, Ain Sokhna, Alexandria, North Coast, Gouna, Giza, and 6th of October. These projects encompass a diverse range of types, including residential, commercial, administrative, renovation, educational, and power station construction. Subset of these projects were examined in detail to highlight the data collection process and provide insights into their schedules and budgets.

In the following chapter (Chapter 5), we will delve into the data analysis techniques that will be applied to this dataset. These techniques include the earned schedule method, earned duration method, and planned value method, each of which will be discussed in detail to provide a comprehensive understanding of the project performance metrics and trends.

Chapter 5: Analysis

In this chapter, We compare the three methods of EVM which are earned schedule method, earned duration method, and planned value method on 30 actual projects in order to find an accurate estimation of the finish date and define which method fits best in different cases. The projects have different types such as commercial, industrial, educational, residential, renovation and administrative. These projects are located in different cities across Egypt such as Cairo, Giza, 6th of October, Ain Sokhna, Hurghada, North coast and Alexandria. These projects have different timelines ranging from 2015 to 2023, in addition to different contract prices. All these projects were evaluated from the contractor's point of view. The projects data were collected from various contractors across Egypt.

5.1 Demonstrating Calculation Procedures in the Sample Project

The calculations will be remonstrated in one project in order to show how the calculations works, the project used for these calculations is a commercial project with a total budget of 498 million EGP the project started in 06th May 2017 and it was planned to finish on 4th September 2019 and actual finish is 30th November 2020. The Month that will be using the calculations for is 01st November 2018 in which the earned value is 127,800,365 million EGP while the actual cost is 145,807,922 and the planned value is 255,378,951 million EGP.

The analysis incorporated three distinct earned value techniques: Earned Duration method, Earned Schedule method, and Planned Value method. Each method had its own set of metrics to evaluate project performance and forecasting accuracy of calculating finish date:

1- Earned Duration Method:

Earned Duration (ED): This metric indicates the equivalent duration based on the value of work completed. It quantifies the time required to complete the earned value.

In a related context, Jacob and Kane (2004) introduced a concept, earned duration (ED), which is the result of multiplying the actual project duration (AD) by the schedule performance index (SPI). Jacob (2003) and Jacob and Kane (2004) advocated for the earned duration method as a robust approach for forecasting a project's final duration by incorporating the schedule performance index (SPI).

The earned duration is calculated using the following formula.

$$\text{ED Earned Duration} = \text{AD X SPI}$$

The actual duration AD is 544 days and the SPI = $\frac{EV}{PV} = \frac{127,800,365}{255,378,951}$ = 50%

Then the Earned duration is calculated ED = 50% x 544 = 272 Days

After that estimate at completion is calculated using this formula EDAC = $AC + \frac{\text{PD}-\text{ED}}{PF}$

PD is the planned total duration of the project which is 851 days and earned duration is 272 days.

The estimate at completion will be calculated three times, the first time when the performance factor PF = 1, the second time when the PF is equal to SPI, and the third time when the PF is equal to SCI which schedule cost index.

$EAC_{PF=1}$=$544 + \frac{851-2}{1}$ = 1123 Days

At PF = SPI

$EAC_{PF=SPI}$=$544 + \frac{851-2}{0.5}$ = 1702 Days

At PF = SCI

SCI = SPI x CPI

CPI = = $\frac{EV}{AC} = \frac{127,800,365}{145,807,922}$ = 88%

SCI = SPI x CPI = 88% x 50% = 44%

$EAC_{PF=SCI}$=$544 + \frac{851-2}{0.5}$ = 1865 Days

The actual finish date 30th November 2020 and the actual project duration is 1304 days.

Then the three estimates are compared with the actual finish date and the accuracy is calculated

$Accuracy_{PF=1}$ $= 1 - \frac{|\text{AD}-EAC_t|}{AD}$ = = $\frac{|1304-1123|}{1304}$ = 86%

$Accuracy_{PF=SPI}$ $= 1 - \frac{|\text{AD}-EAC_t|}{AD}$ = = $\frac{|1304-1702|}{1304}$ = 69%

$Accuracy_{PF=SCI}$ $= 1 - \frac{|\text{AD}-EAC_t|}{AD}$ = = $\frac{|1304-1865|}{1304}$ = 57%

Therefore, the highest accuracy achieved when the PF = 1

2- Planned Value Method:

Anbari (2003) developed the planned value method, which relies on established earned value metrics to project a project's duration. This method calculates the average planned value per time period, known as the planned value rate (PVrate). PVrate is determined by dividing the project's baseline budget at completion (BAC) by its planned duration (PD). This metric helps translate schedule variance (SV) into time units, represented as time variance (TV).

First planned value rate is calculated as shown below:

$$PV_r = \frac{BAC}{PD} = \frac{498{,}371{,}317}{851} = 585{,}630$$

Then time variance is calculated.

$$TV = \frac{SV}{PV_r}$$

SV = EV – PV = 127,800,365 - 255,378,951 = -127,579,585 EGP

$$TV = \frac{-1 \quad ,579{,}585}{585{,}630} = \text{-218 days}$$

After that estimate at completion is calculated when the performance factor = 1 using this formula

$TEAC_{PF=1}$= PD – TV = 851 – (-218) = 1069 days

At PF = SPI

Time variance is calculated using this formula $TEAC = \frac{PD}{SPI} = \frac{851}{50\%} = 1702$ days

At PF = SCI

The time variance is calculated using this formula $TEAC = \frac{PD}{SCI} = \frac{851}{44\%} = 1942$ days

Then the three estimates are compared with the actual finish date and the accuracy is calculated

$$Accuracy_{PF=1} = 1 - \frac{|\mathrm{AD} - EAC_t|}{AD} = = \frac{|1304-1069|}{1304} = 82\%$$

$$Accuracy_{PF=SPI} = 1 - \frac{|\mathrm{AD} - EAC_t|}{AD} = = \frac{|1304-1702|}{1304} = 69\%$$

$$Accuracy_{PF=SCI} = 1 - \frac{|\mathrm{AD} - EA \quad t|}{AD} = = \frac{|1304-1942|}{1304} = 51\%$$

Therefore, the highest accuracy achieved with planned value method is when PF = 1

3- Earned Schedule Method:

Earned Schedule (ES): ES represents the time when the value of the work is earned. It is calculated using the following formula:

$$ES = \mathrm{t} + \frac{\mathrm{EV} - P \quad t}{PV_{t+1} - PV_t} = 544 + \frac{127{,}800{,}365 - 127{,}263{,}050}{144{,}674{,}198 - 127{,}263{,}050} = 330 \text{ Day}$$

To calculate the Estimate at completion in time units the equation is as follows:

First at PF = 1,

$$EAC_{PF=1} = AT + \frac{\text{PDWR}}{PF} = AT + \frac{\text{PD}-\text{ES}}{PF} = 544 + \frac{851-330}{1} = 1065 \text{ day}$$

at PF = SPI,

$$EAC_{PF=S} = AT + \frac{\text{PDWR}}{PF} = AT + \frac{\text{PD}-\text{ES}}{PF} = 544 + \frac{85}{50\%} = 1403 \text{ day}$$

at PF = SCI,

$$EAC_{PF=S} = AT + \frac{\text{PDWR}}{PF} = AT + \frac{\text{PD}-\text{ES}}{PF} = 544 + \frac{851-330}{44\%} = 1524 \text{ day}$$

Comparing the result with the actual finish date, the accuracy is determined as shown below.

$$Accuracy_{PF=1} = 1 - \frac{|\text{AD}-EAC_t|}{AD} = = \frac{|1304-1065|}{1304} = 82\%$$

$$Accuracy_{PF=S} = 1 - \frac{|\text{AD}-E \quad t|}{AD} = = \frac{|1304-1403|}{1304} = 92.4\%$$

$$Accuracy_{PF=SCI} = 1 - \frac{|\text{AD}-EAC_t|}{AD} = = \frac{|1304-152 \quad |}{1304} = 83\%$$

Therefore, the highest accuracy achieved with earned schedule is when PF = SPI, in addition to being the highest accuracy obtained

Following the project calculations, the results will be presented in four figures. These figures will depict the project duration percentages under different scenarios: first, when the performance factor is set to 1; second, when the performance factor is configured to SPI; third, when the performance factor is set to SCI; and finally, a comprehensive comparison figure to assess the overall estimation. This comparison will highlight the most suitable technique to employ based on the performance factor.

figure 6 presents an average comparison among the three techniques for the demonstrative project. As depicted, the Earned Schedule method demonstrates consistent accuracy between 75% and 90% throughout the project duration. In contrast, the Earned Duration method exhibits a decline from 20% to 75% of the project duration, followed by a subsequent increase leading to its peak accuracy at the conclusion of the project. Likewise, the Planned Value method experiences a decrease from 20% to 75% of the project duration, reaching its lowest accuracy among the three techniques by the project's end.

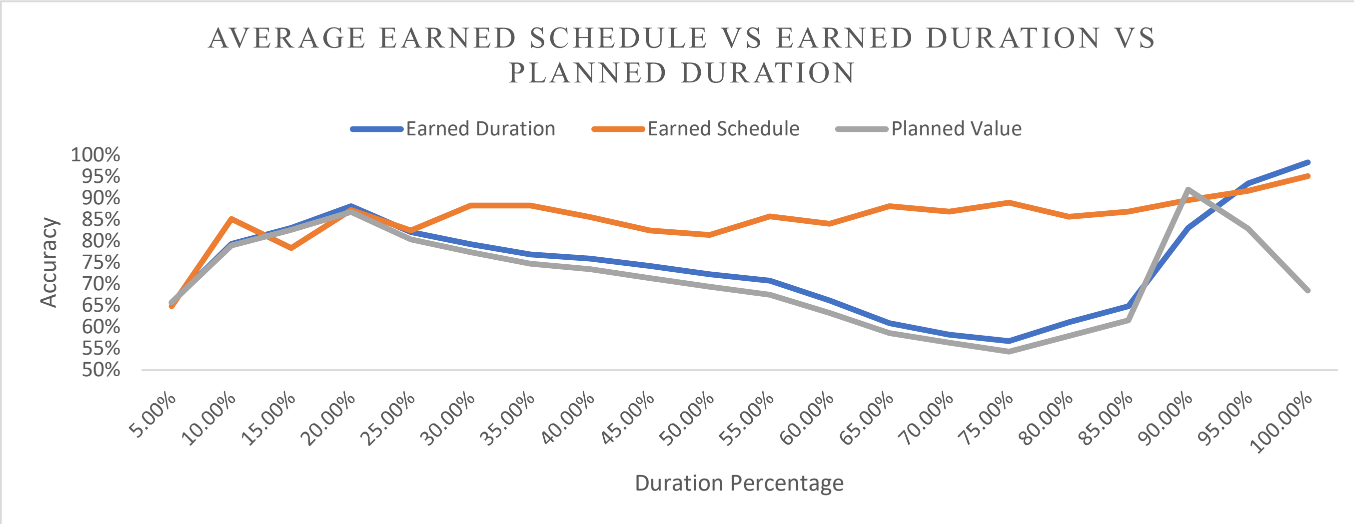

Figure 6 Average Earned Schedule VS earned Duration VS Planned Duration

Figure 7 offers a comparative assessment of the three techniques when the performance factor is equal to 1. Initially, all three methods exhibited nearly identical accuracy, hovering around 65%. Subsequently, as the project duration percentage advanced to 85%, all methods showed a continuous increase. However, a notable divergence occurred thereafter: the Planned Value method began to decline, reaching approximately 69% towards the project's conclusion. In contrast, the Earned Schedule method achieved a 97.5% accuracy by the project's end, while the Earned Duration method reached the highest percentage, standing at 98.5% at the conclusion of the project.

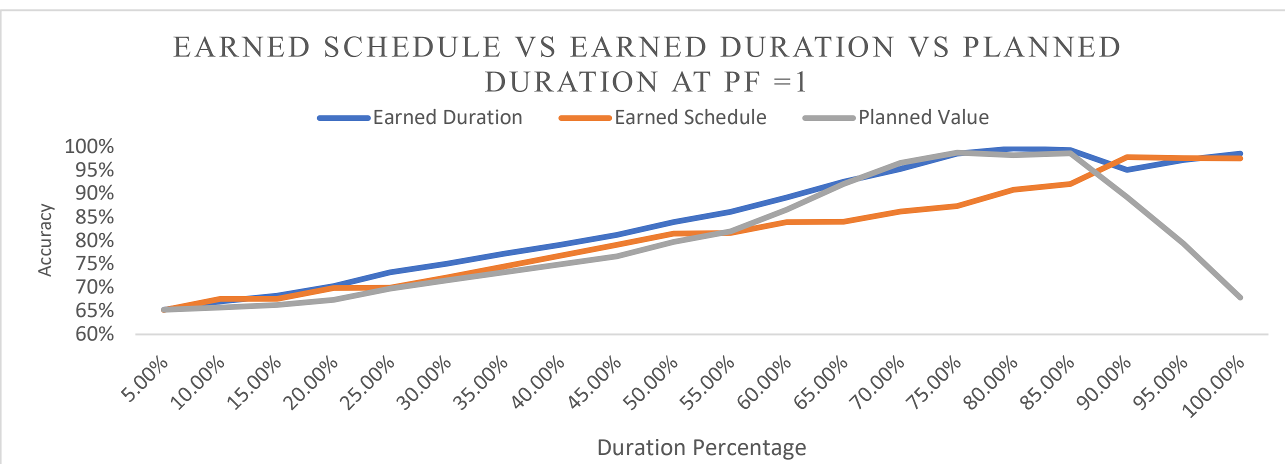

Figure 7 Average accuracy Earned schedule vs earned duration vs planned duration At PF = 1

Figure 8 provides a comparative evaluation of the three techniques when the performance factor is set to SPI. Initially, all three methods demonstrated nearly identical accuracy, hovering around 65%. As the project duration percentage advanced to 20%, all three methods experienced an increase. However, a divergence emerged after this point: the Planned Duration and Earned Duration methods gradually decreased, reaching their lowest points around the 75% duration mark. In contrast, the Earned Schedule method-maintained accuracy between 85% and 95% throughout the project duration, concluding with a 94% accuracy. Towards the end of the project, the Earned Duration method exhibited an increase, reaching 98%, while the Planned Value method declined, concluding with a 68% accuracy.

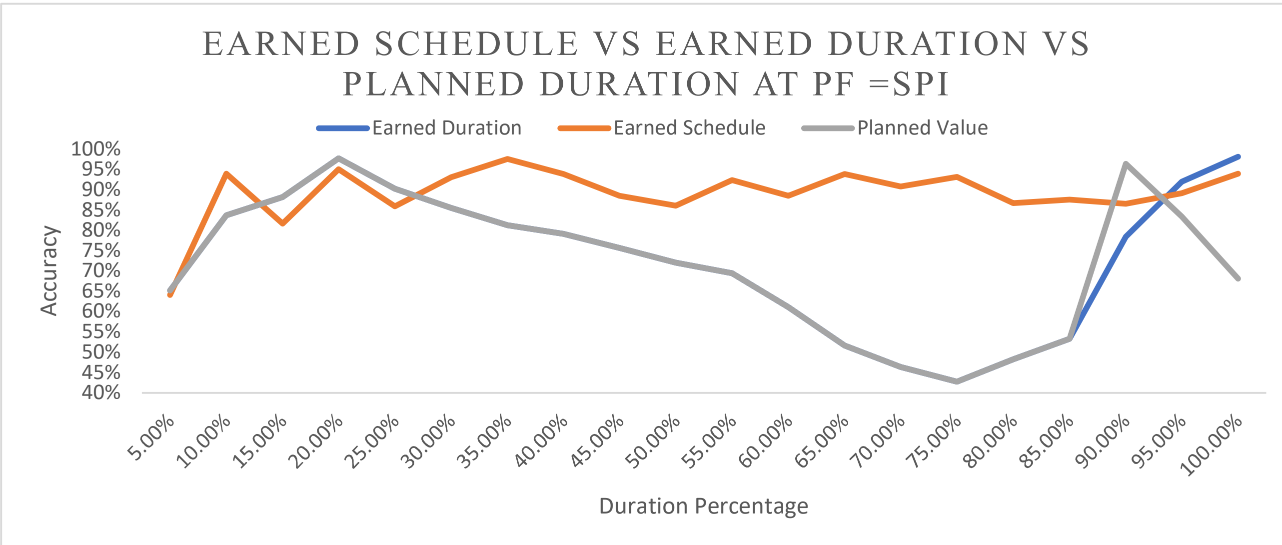

Figure 8 Average accuracy Earned schedule vs earned duration vs planned duration At PF = SPI

Figure 9 conducts a comparative assessment of the three techniques with the performance factor set to SCI. Initially, all three methods demonstrated virtually identical accuracy, hovering around 65%. As the project duration percentage progressed to 20%, two methods, namely Earned Schedule and Planned Value, exhibited an increase, maintaining accuracy between 80% and 95% throughout the project duration and culminating in a 94% accuracy by the project's conclusion. In contrast, Earned Duration experienced a decline, reaching 29% at the 75% mark of the project duration percentage. Subsequently, it underwent an upward trend, reaching 98% by the conclusion of the project.

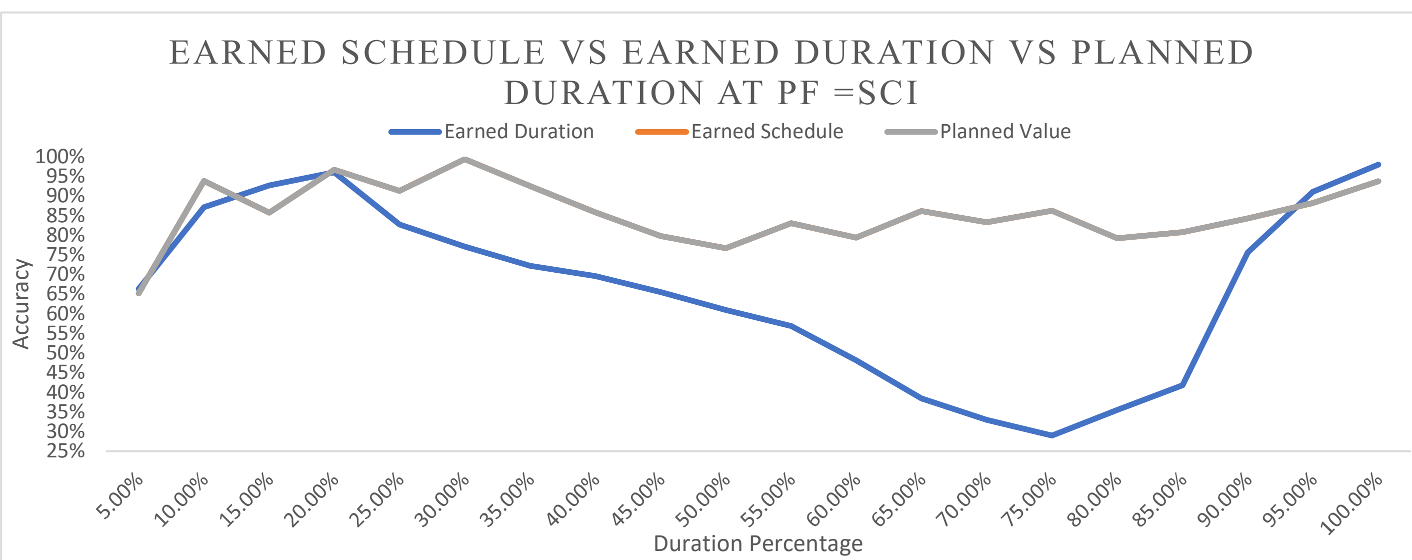

Figure 9 Average accuracy Earned schedule vs earned duration vs planned duration At PF = SCI

- However, it's worth noting that the choice of the most effective technique also depends on the specific project type and its duration. For renovation and residential projects, the Earned Schedule method outperformed the others, achieving the highest accuracy. On the other hand, for industrial, commercial, and educational, the Earned Duration method was consistently the most accurate.

5.2 The Analysis of Industrial Projects.

The detailed discussion of the outcomes for each project type begins with industrial projects. As previously noted, the Earned Duration method yields the highest overall percentage. However, when the performance factor is set to SPI, Earned Schedule takes the lead in accuracy. The following illustration provides a comprehensive overview of accuracy percentages across project duration percentages, considering performance factors 1, SPI, SCI, and the average.

Figure 10 depicts the accuracy comparison among the three methods on an average basis.

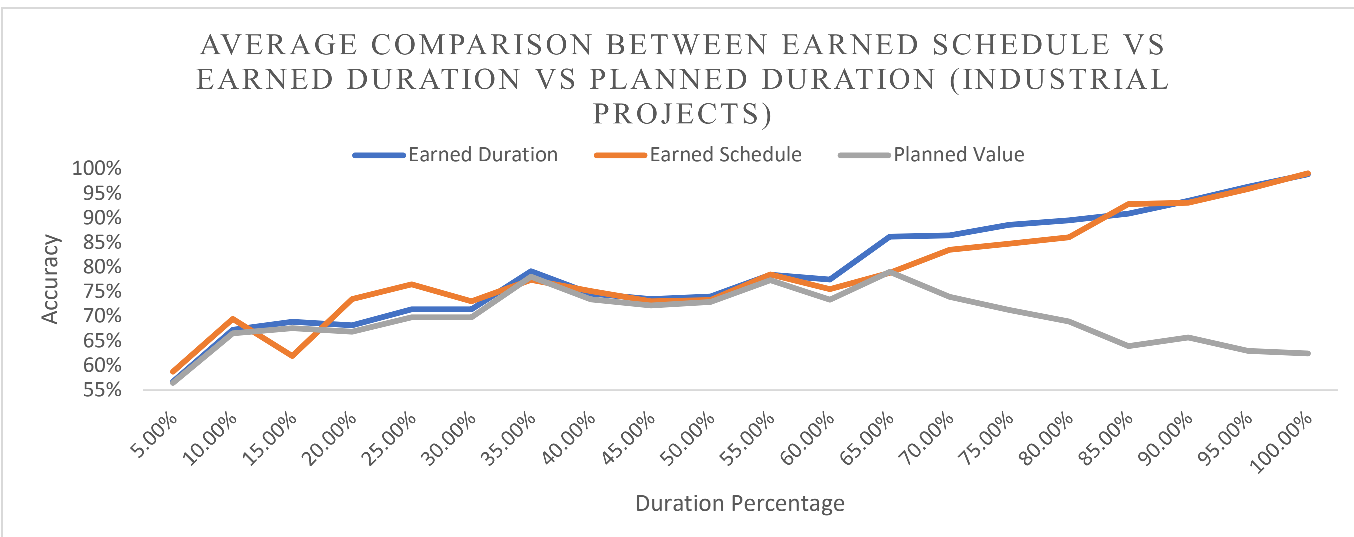

Figure 10 Average Accuracy between Earned Schedule vs Earned duration vs Planned duration (Industrial Projects)

Figure 11 illustrates the comparison of accuracy among the three methods under the condition of a performance factor set to 1.

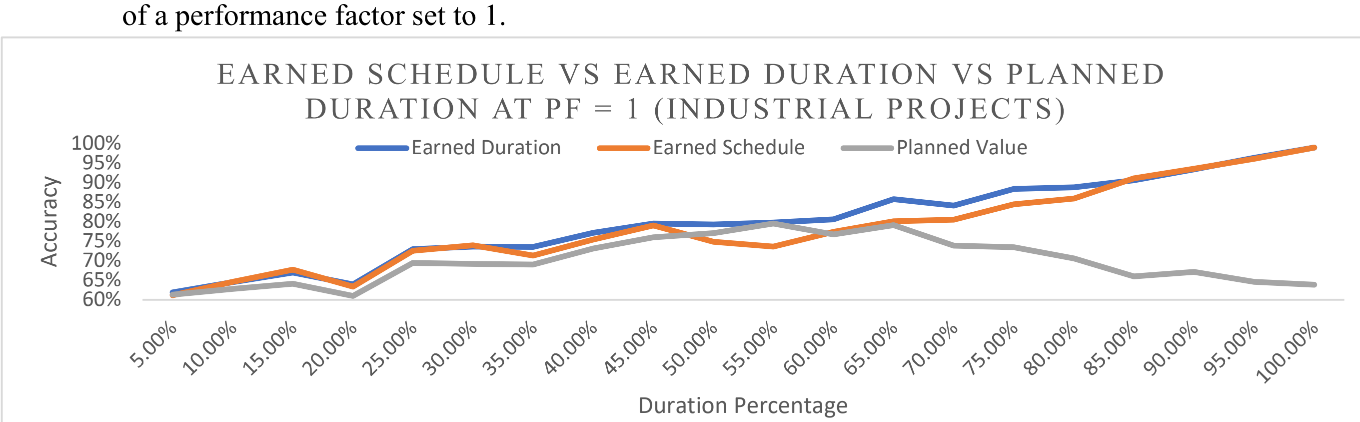

Figure 11 Accuracy comparison between Earned Schedule vs Earned duration vs Planned duration (Industrial Projects) AT PF = 1

Figure 12 displays the accuracy comparison among the three methods when the performance factor is set to SPI.

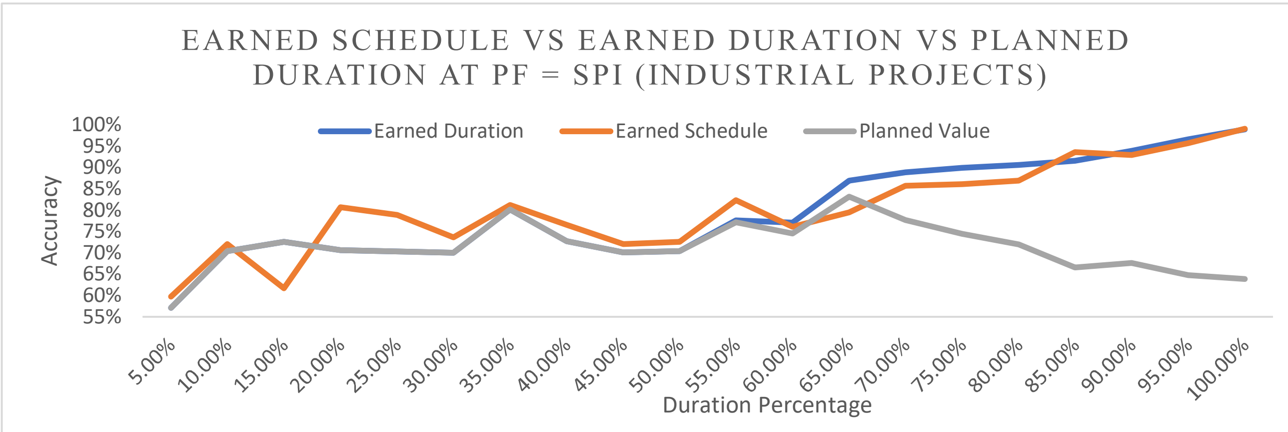

Figure 12 Average comparison between Earned Schedule vs Earned duration vs Planned duration (Industrial Projects) AT PF =SPI

Figure 13 displays the accuracy comparison among the three methods when the performance factor is set to SCI.

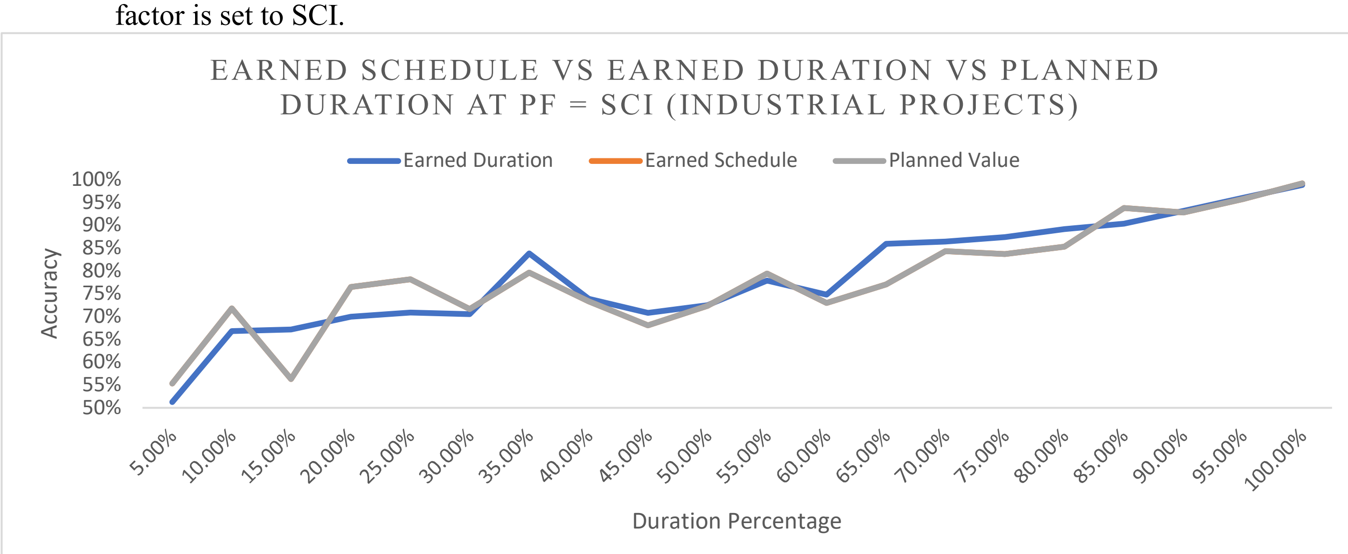

Figure 13 Average comparison between Earned Schedule vs Earned duration vs Planned duration (Industrial Projects) at PF = SI

5.3 The Analysis of Commercial Projects.

Similarly, in commercial projects, the Earned Duration method attains the highest overall percentage, and this trend persists when the performance factor is set to 1. Conversely, when the performance factor is SPI, the highest accuracy percentage is achieved by the Earned Schedule method. The forthcoming illustration will present a comprehensive overview of accuracy percentages across project duration percentages for performance factors 1, SPI, SCI, and the average.

Figure 14 illustrates the comparison of accuracy among the three methods on an average scale.

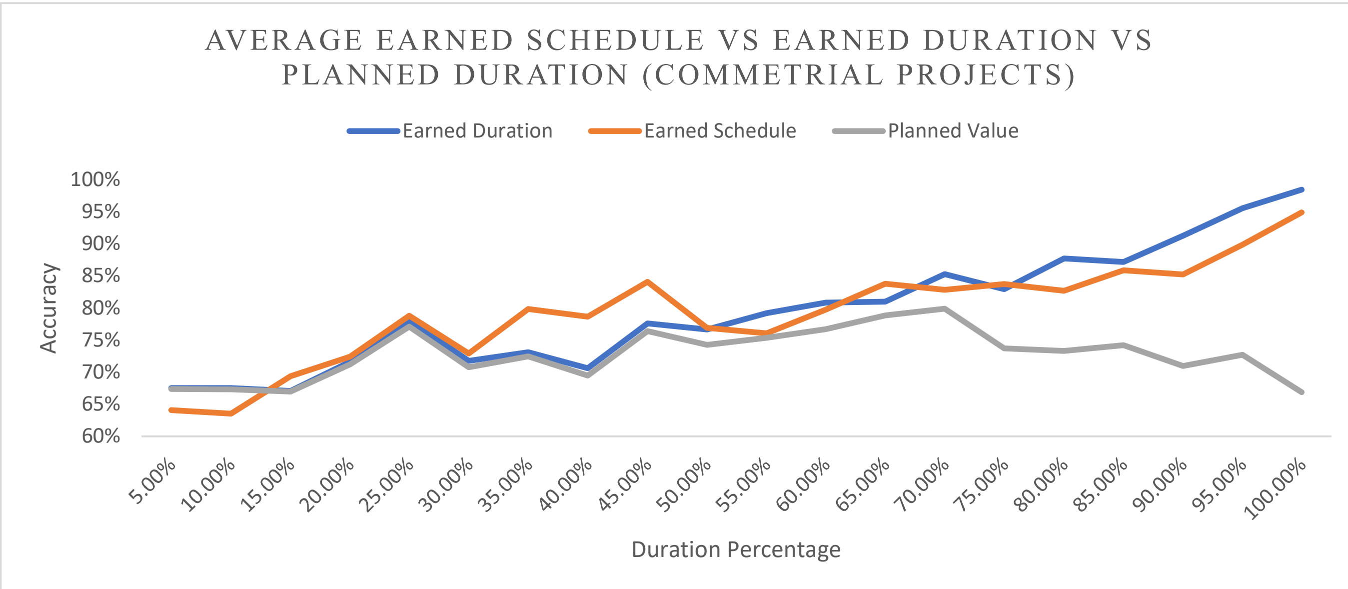

Figure 14 Average Earned Schedule vs Earned duration vs Planned duration (Commetrial Projects)

Figure 15 depicts the accuracy comparison among the three methods when the performance factor is set to 1.

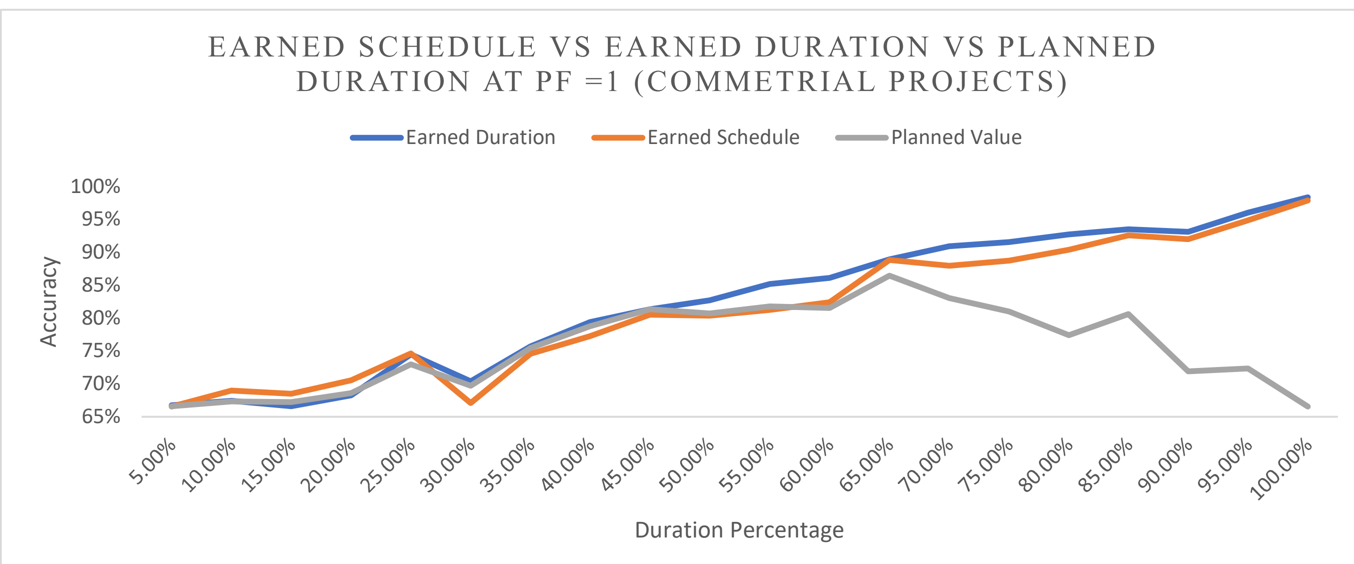

Figure 15 Average Earned Schedule vs Earned duration vs Planned duration (Commetrial Projects) at PF = 1

Figure 16 showcases the accuracy comparison among the three methods when the performance factor is configured to SPI.

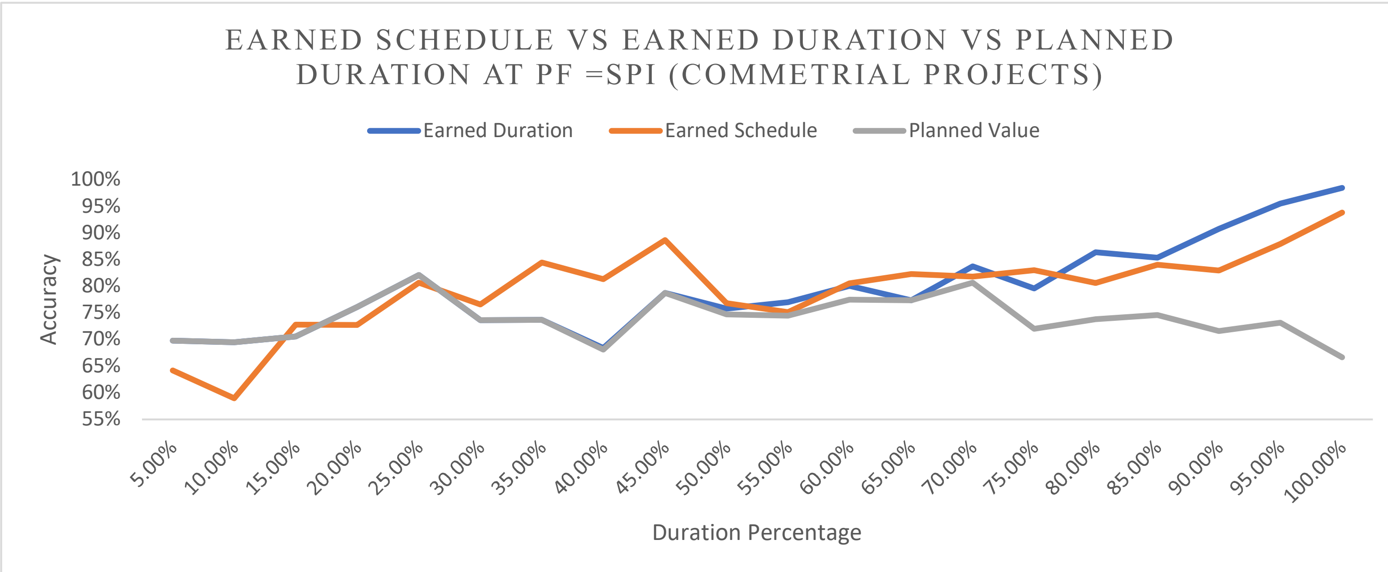

Figure 16 Average Earned Schedule vs Earned duration vs Planned duration (Commercial Projects) at PF = SPI

Figure 17 is visual representation for the commercial projects highlights the accuracy comparison when the performance factor is set to SCI.

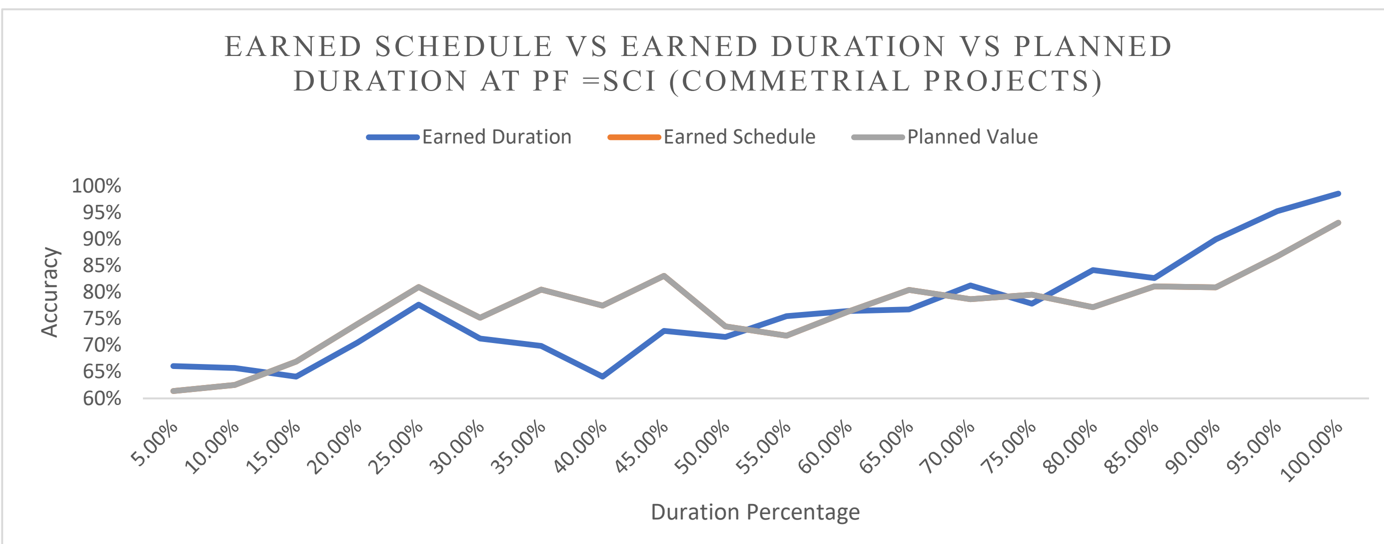

Figure 17 Average Earned Schedule vs Earned duration vs Planned duration (Commercial Projects) AT PF = SCI

5.4 The Analysis of Educational Projects.

In the case of educational projects, the Earned Duration method achieves the highest overall percentage. Additionally, when the performance factor is set to SPI and SCI, Earned Duration maintains its supremacy. However, under the condition of a performance factor equal to 1, Earned Schedule exhibits the highest accuracy. The upcoming visual representation will provide a thorough overview of accuracy percentages across project duration percentages for performance factors 1, SPI, SCI, and the average.

Figure 18 depiction showcases the comparison of accuracy among the three methods on an average scale.

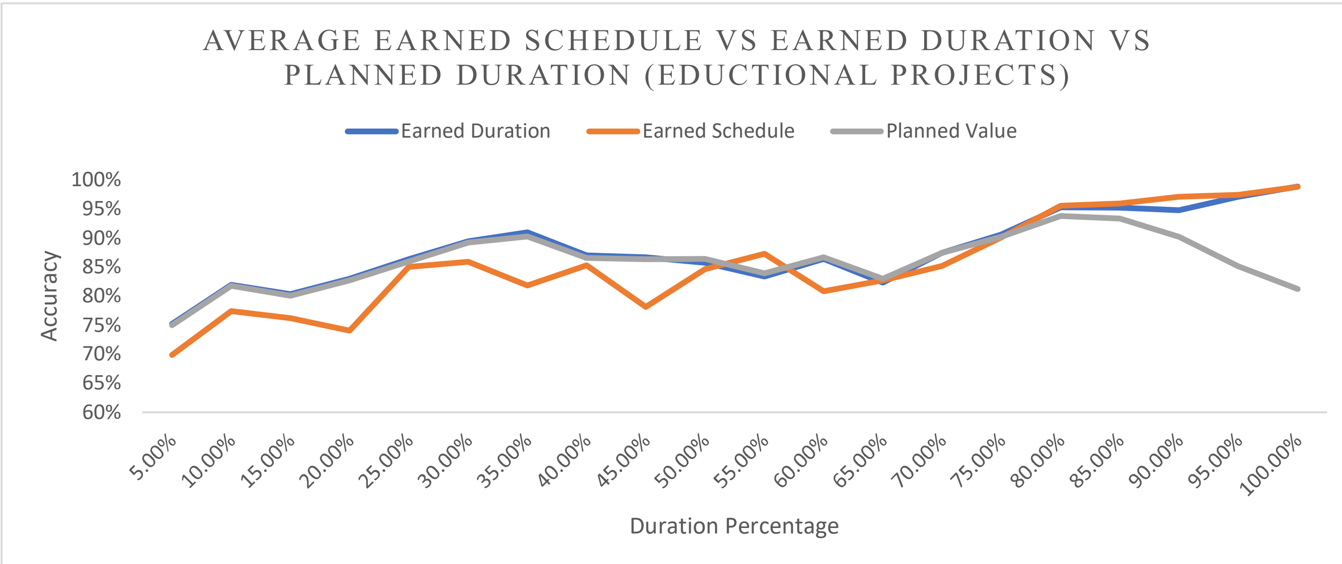

Figure 18 Average Earned Schedule vs Earned duration vs Planned duration (Educational projects)

Figure 19 illustrates the accuracy comparison among the three methods under the condition of a performance factor set to 1.

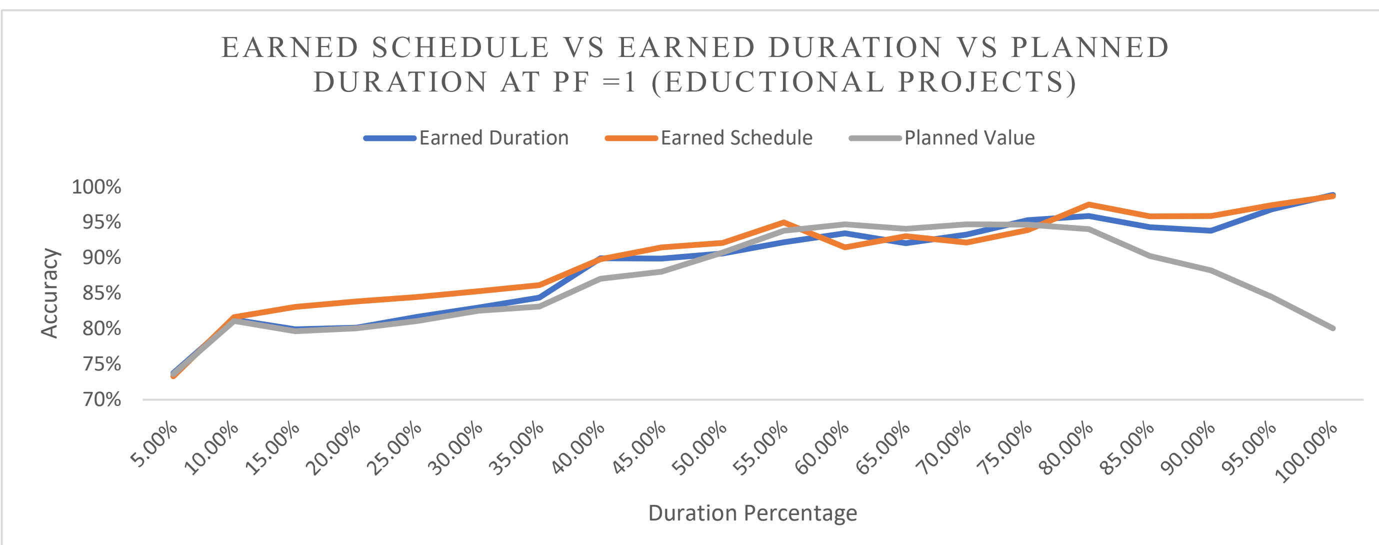

Figure 19 Earned Schedule vs Earned duration vs Planned duration at PF =1 (Educational projects)

Figure 20 presents the accuracy comparison among the three methods when the performance factor is set to SPI.

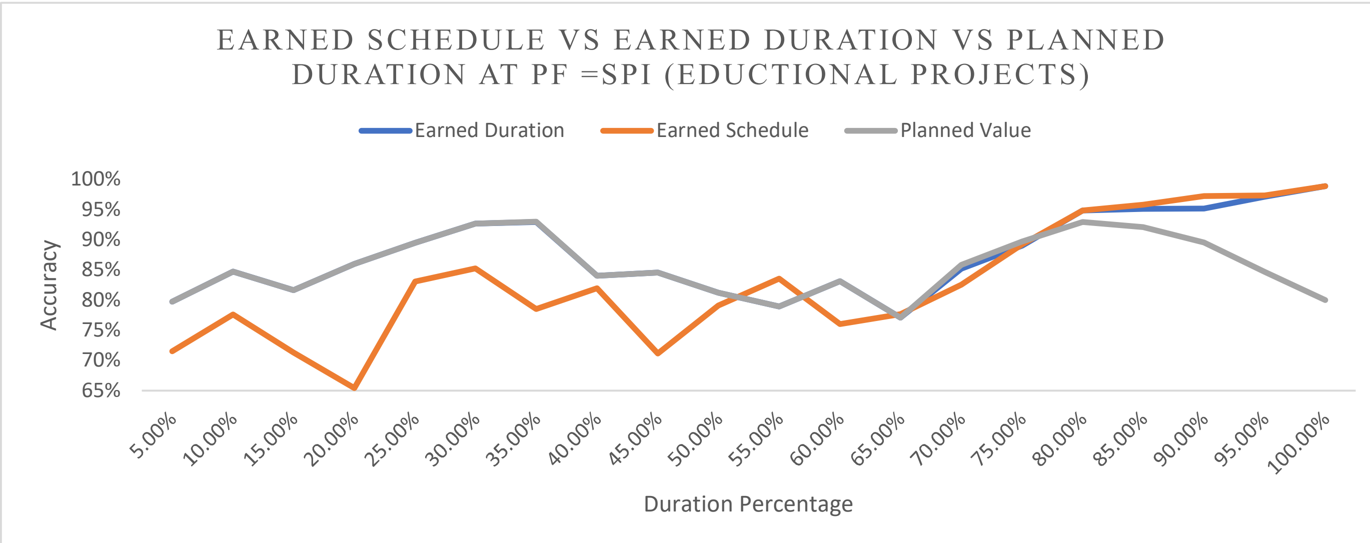

Figure 20 Earned Schedule vs Earned duration vs Planned duration (Educational projects) at PF = SPI

Figure 21 is the visual representation for the commercial projects underscores the accuracy comparison when the performance factor is set to SCI.

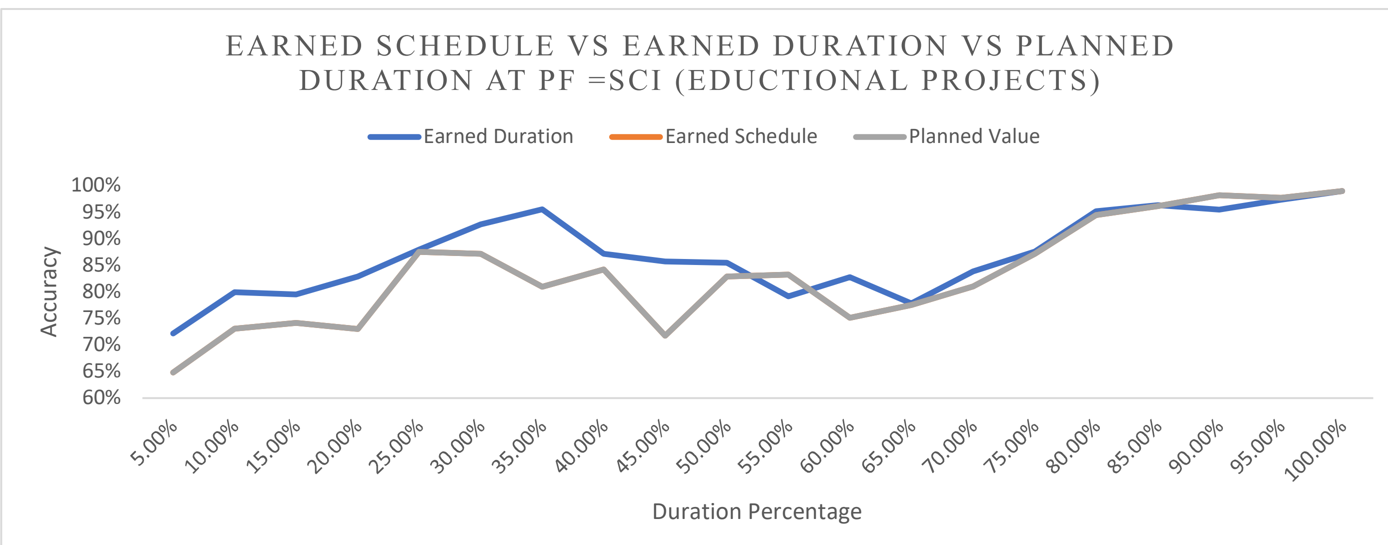

Figure 21 Earned Schedule vs Earned duration vs Planned duration (Educational projects) AT PF = SCI

5.5 The Analysis of Residential Projects.

For residential projects, in contrast to other projects, the Earned Schedule method secures the highest overall percentage. Furthermore, under the conditions of a performance factor set to 1, SPI, and SCI, the upcoming visual representation will deliver a comprehensive overview of accuracy percentages across project duration percentages for performance factors 1, SPI, SCI, and the average.

Figure 22 highlights the comparison of accuracy among the three methods on an average scale.

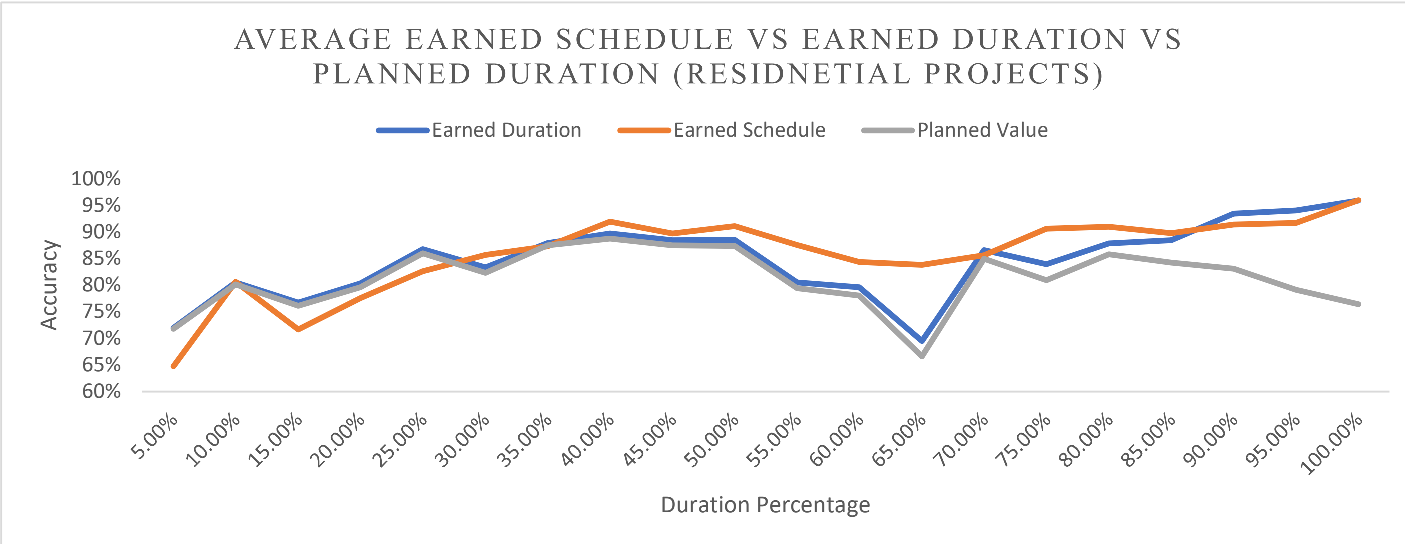

Figure 22Average Earned Schedule vs Earned duration vs Planned duration (Residential projects)

Figure 23 illustrates the comparison of accuracy among the three methods when the performance factor is set to 1.

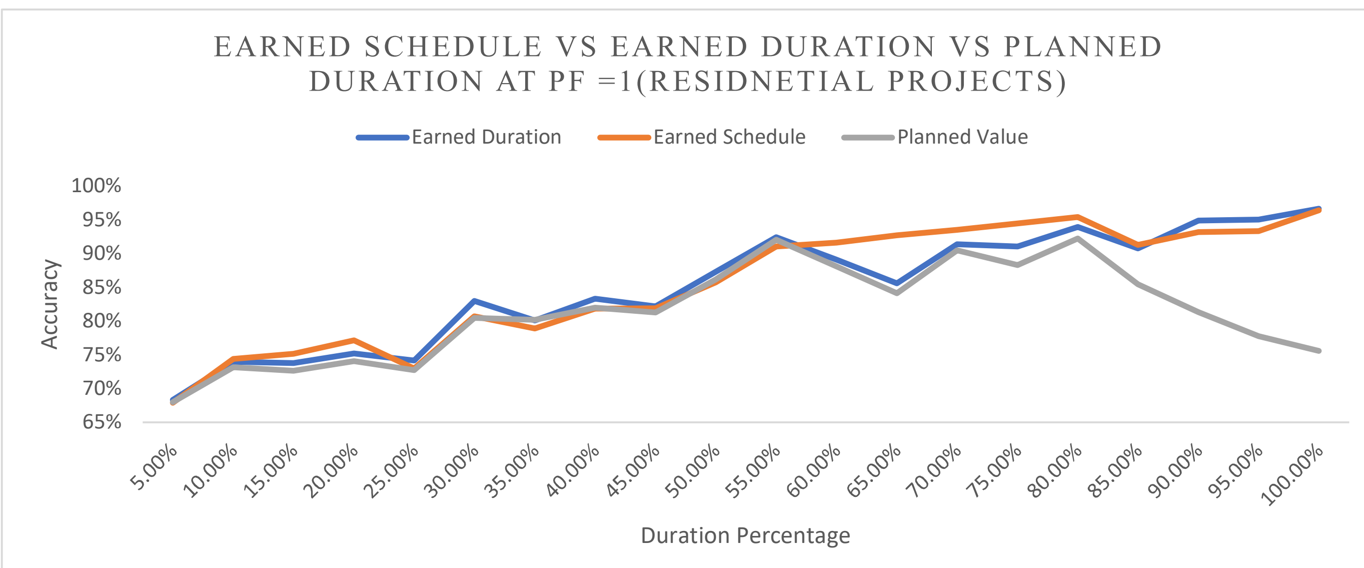

Figure 23 Average Earned Schedule vs Earned duration vs Planned duration (Residential projects) AT PF = 1

Figure 24 showcases the accuracy comparison among the three methods when the performance factor is configured to SPI.

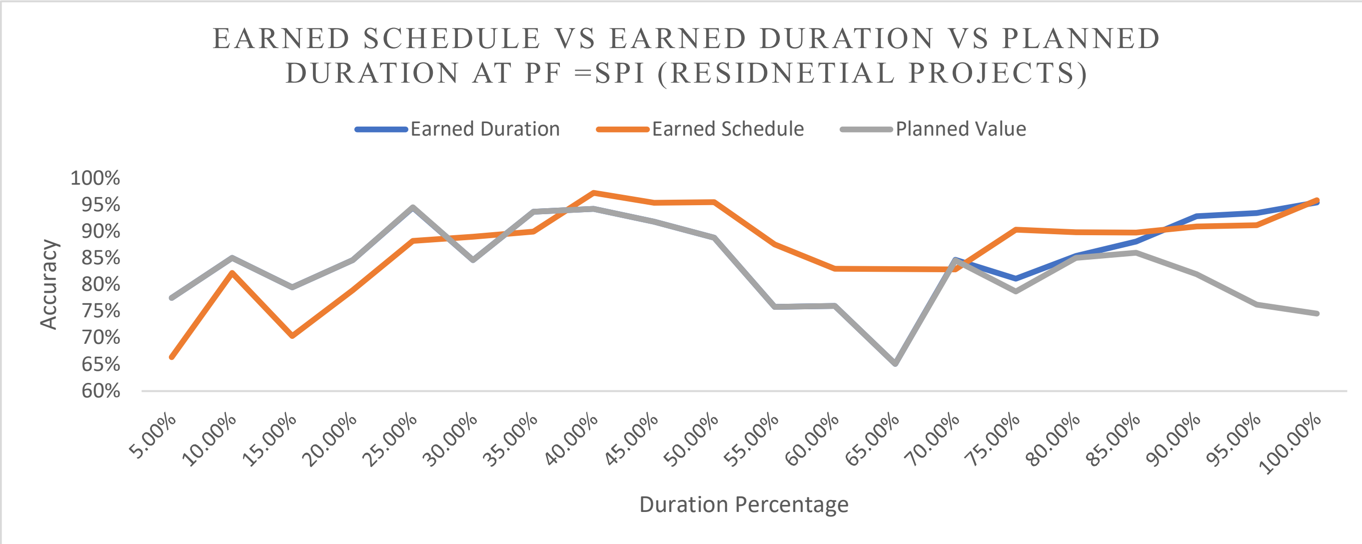

Figure 25 is the visual representation for commercial projects emphasizes the accuracy comparison when the performance factor is set to SCI.

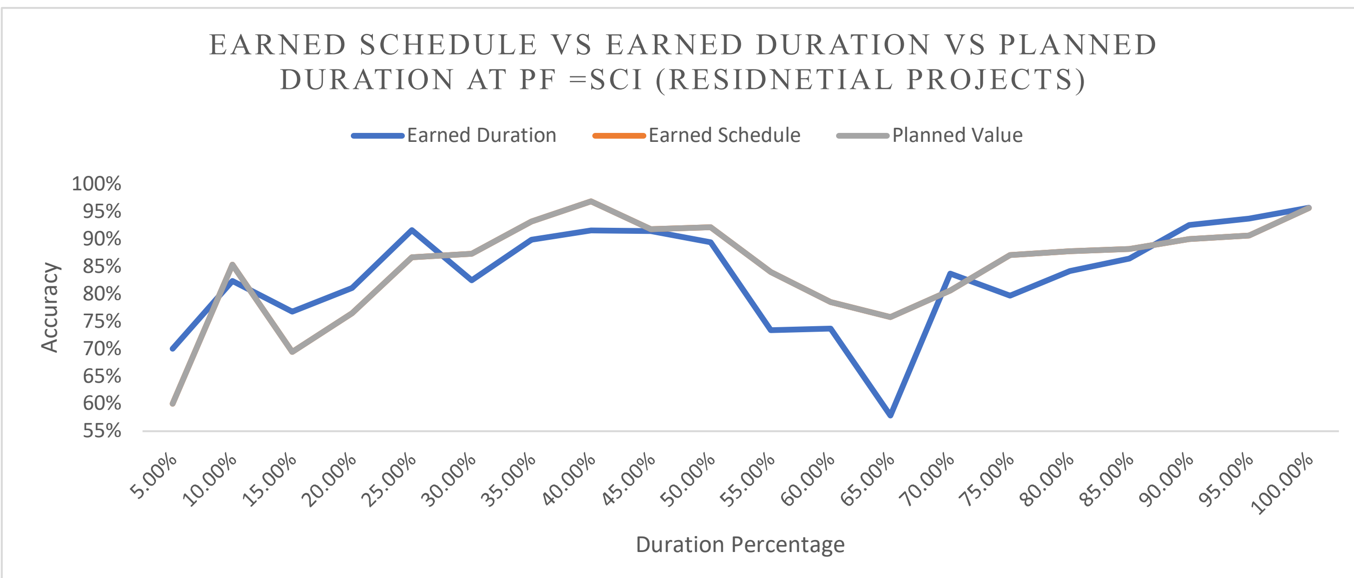

Figure 25 Earned Schedule vs Earned duration vs Planned duration (Residential projects) AT PF = SCI

5.6 The Analysis of Renovation Projects.

In renovation endeavours, much like residential projects, the Earned Schedule method consistently achieves the highest overall percentage. Additionally, when the performance factor is set to 1, the earned duration takes precedence, while equality between the performance factor, SPI, and SCI results in the earned duration coming out on top. A forthcoming visual representation will provide a comprehensive overview of accuracy percentages across project duration percentages for performance factors 1, SPI, SCI, and the average.

Figure 26 emphasizes the comparison of accuracy among the three methods on an average scale.

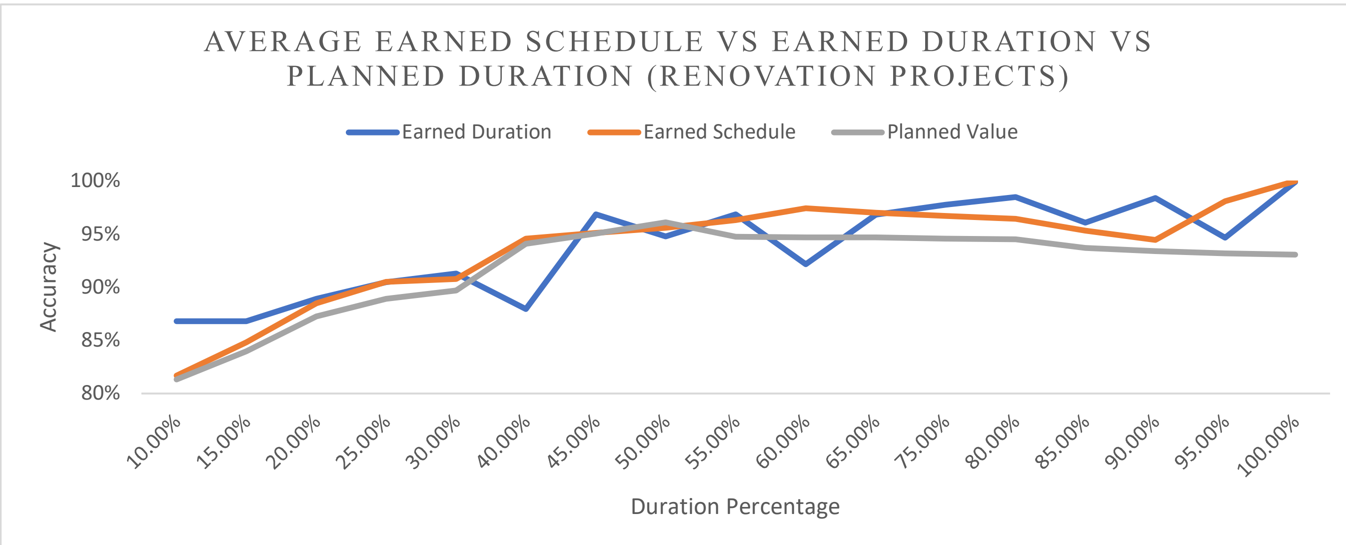

Figure 26 Average Earned Schedule vs Earned duration vs Planned duration (Renovation projects)

Figure 27 depicts a comparison of accuracy among the three methods under the condition of a performance factor set to 1.

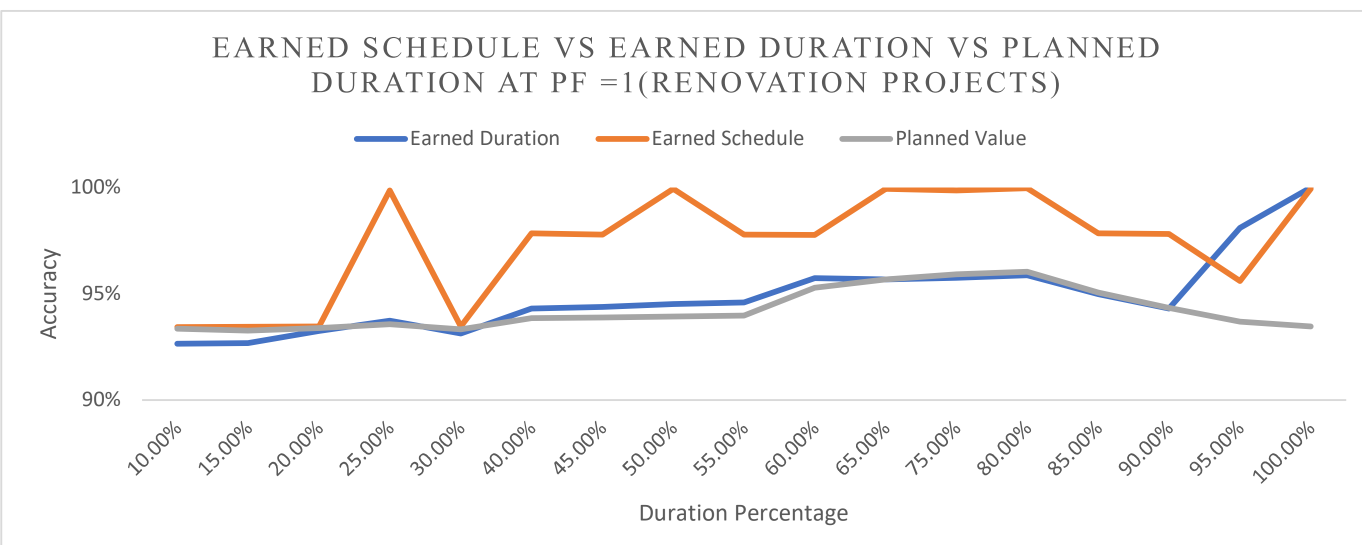

Figure 27 Earned Schedule vs Earned duration vs Planned duration (Renovation projects) AT PF =1

Figure 28 displays a comparison of accuracy among the three methods under the configuration of the performance factor to SPI.

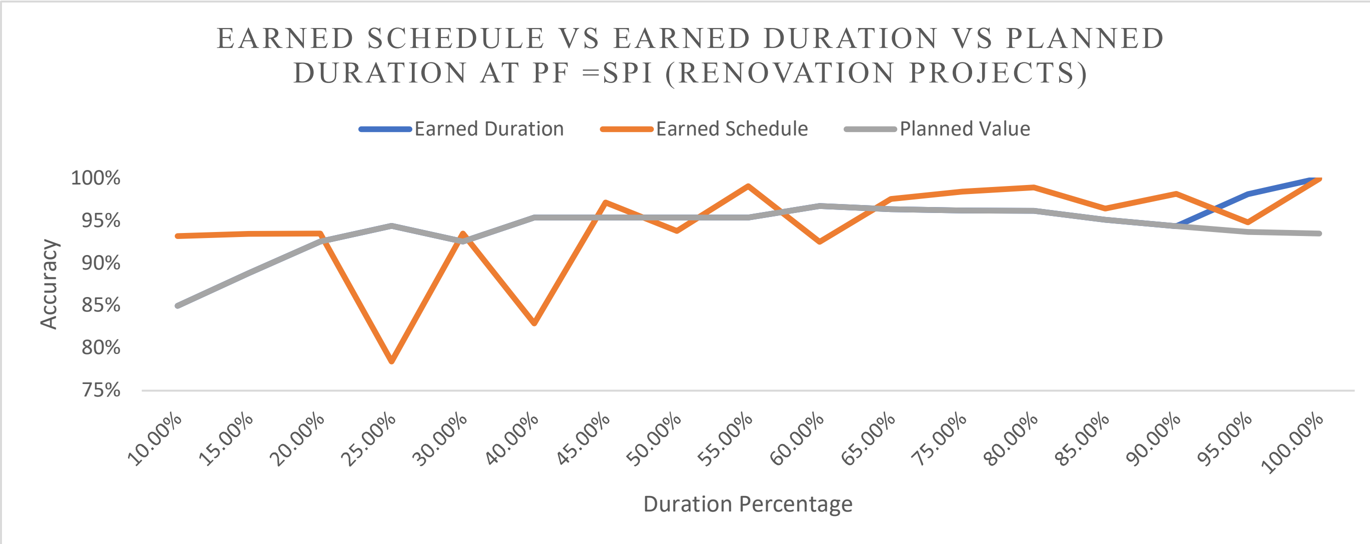

Figure 28 Average Earned Schedule vs Earned duration vs Planned duration (Renovation projects) AT PF = SPI

Figure 29 is the visual representation for commercial projects emphasizes the accuracy comparison when the performance factor is set to SCI.

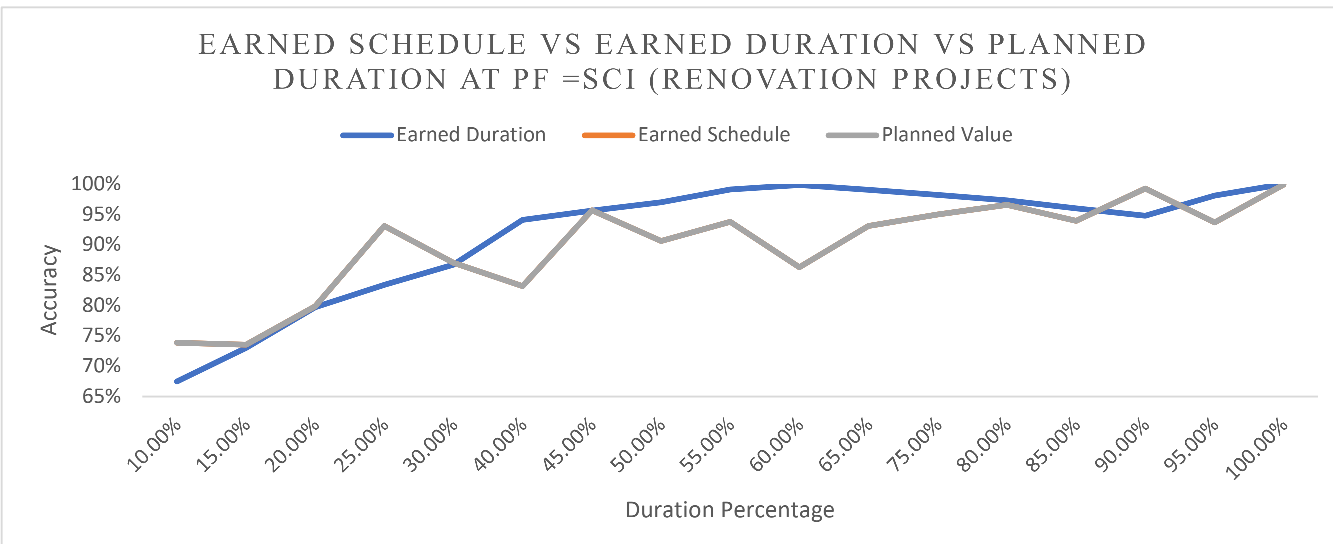

Figure 29 Average Earned Schedule vs Earned duration vs Planned duration (Renovation projects) AT PF = SCI

In summary, the analysis of various project types reveals distinct patterns in the performance of Earned Duration and Earned Schedule methods under different performance factors. In industrial projects, Earned Duration consistently secures the highest overall percentage, except when the performance factor is set to SPI, where Earned Schedule excels in accuracy. A similar trend is observed in commercial projects, with Earned Duration dominating overall and Earned Schedule leading under the SPI performance factor. Educational projects showcase a nuanced scenario, where Earned Duration performs best overall but Earned Schedule surpasses under a performance factor set to 1. Notably, residential and renovation projects deviate from the general pattern, with Earned Schedule emerging as the method with the highest overall percentage. The detailed visual representations across project duration percentages and performance factors 1, SPI, SCI, and the average offer a comprehensive overview, aiding in understanding the nuanced dynamics of accuracy across diverse project types and conditions.

5.7 International and domestic project managers

Another crucial criterion employed for the analysis involves assessing the accuracy by comparing projects managed by international and domestic project managers. This aims to underscore potential disparities between these two factors. Table 3 illustrates the variance in accuracy between domestic and international project managers when using performance factor equal to 1. As depicted in the table, projects led by international project managers consistently exhibit higher accuracy levels compared to those overseen by domestic counterparts throughout the project timeline.

Table 3 Comparison between international and domestic project managers when performance factor equal to 1

Duration %	PM	Accuracy At PF = 1			PM	Accuracy At PF = 1		
		ED	ES	PV		ED	ES	PV
5%	International	75.23%	74.37%	74.64%	Domestic	64.58%	64.50%	64.40%
10%	International	74.63%	75.06%	73.15%	Domestic	69.82%	70.82%	69.48%
15%	International	79.06%	81.04%	76.92%	Domestic	68.53%	70.21%	68.47%
20%	International	75.05%	75.40%	72.52%	Domestic	69.56%	71.84%	69.38%
25%	International	78.74%	78.90%	76.18%	Domestic	75.17%	76.17%	74.04%
30%	International	77.86%	73.94%	74.78%	Domestic	75.34%	74.69%	74.51%
35%	International	78.54%	77.11%	74.61%	Domestic	77.18%	75.77%	76.85%
40%	International	82.40%	80.71%	78.59%	Domestic	81.71%	80.75%	81.47%
45%	International	85.06%	84.10%	81.32%	Domestic	81.62%	82.03%	81.49%
50%	International	84.98%	81.05%	82.80%	Domestic	84.74%	85.16%	84.12%
55%	International	87.67%	81.11%	86.63%	Domestic	85.91%	86.38%	85.46%
60%	International	88.11%	84.76%	85.47%	Domestic	86.10%	85.62%	84.48%
65%	International	89.99%	86.79%	85.75%	Domestic	88.38%	89.92%	86.14%
70%	International	89.01%	85.75%	83.15%	Domestic	90.65%	89.32%	84.47%
75%	International	92.19%	89.32%	83.78%	Domestic	91.18%	90.40%	82.77%
80%	International	93.22%	90.59%	84.12%	Domestic	92.44%	92.55%	80.39%
85%	International	93.64%	94.11%	81.25%	Domestic	93.27%	92.32%	78.77%
90%	International	95.80%	95.55%	77.61%	Domestic	93.59%	94.28%	74.19%
95%	International	97.56%	96.91%	72.71%	Domestic	96.42%	96.41%	73.68%
100%	International	99.18%	98.93%	70.56%	Domestic	99.12%	98.79%	68.22%

Table 4 presents the discrepancy in accuracy between domestic and international project managers when utilizing the performance factor equivalent to SPI. As indicated in the table, projects supervised by international project managers consistently demonstrate higher accuracy levels in comparison to those managed by domestic counterparts throughout the project timeline.

Table 4 Comparison between international and domestic project managers when performance factor equal to 1

Duration %	PM	Accuracy At PF = SPI			PM	Accuracy At PF = SPI		
		ED	ES	PV		ED	ES	PV
5%	International	72.43%	71.29%	72.43%	Domestic	68.04%	64.21%	68.04%
10%	International	79.15%	64.98%	79.15%	Domestic	73.79%	69.60%	73.79%
15%	International	80.29%	71.99%	80.29%	Domestic	72.99%	74.13%	72.99%
20%	International	82.68%	86.37%	82.68%	Domestic	77.00%	71.44%	77.00%
25%	International	81.69%	86.27%	81.69%	Domestic	85.55%	79.28%	85.55%
30%	International	78.78%	76.75%	78.78%	Domestic	77.70%	85.81%	77.70%
35%	International	85.51%	86.51%	85.51%	Domestic	76.15%	85.82%	76.15%
40%	International	83.67%	84.67%	83.67%	Domestic	75.67%	84.62%	75.67%
45%	International	81.23%	83.28%	81.23%	Domestic	81.33%	85.24%	81.30%
50%	International	79.48%	80.37%	79.48%	Domestic	80.62%	79.38%	80.39%
55%	International	77.62%	85.78%	77.34%	Domestic	79.49%	79.31%	79.36%
60%	International	75.36%	79.48%	73.85%	Domestic	82.81%	81.99%	82.37%
65%	International	77.53%	81.77%	75.90%	Domestic	81.23%	81.19%	80.18%
70%	International	86.18%	86.78%	79.97%	Domestic	84.85%	85.36%	81.42%
75%	International	87.12%	88.50%	78.65%	Domestic	82.85%	84.44%	75.89%
80%	International	91.28%	88.28%	82.89%	Domestic	88.36%	85.16%	78.26%
85%	International	92.69%	92.67%	81.53%	Domestic	87.07%	87.46%	74.54%
90%	International	95.88%	93.67%	78.54%	Domestic	92.23%	89.62%	74.18%
95%	International	97.80%	95.41%	72.92%	Domestic	96.01%	93.61%	74.19%
100%	International	99.19%	98.63%	70.51%	Domestic	99.11%	97.79%	68.22%

Table 5 displays the variation in accuracy between domestic and international project managers, utilizing the performance factor equivalent to SCI. As outlined in the table, projects overseen by international project managers consistently showcase higher accuracy levels compared to those managed by their domestic counterparts across the project timeline.

Duration %	PM	Accuracy At PF = SCI			PM	Accuracy At PF = SCI		
		ED	ES	PV		ED	ES	PV
5%	International	66.08%	66.47%	66.47%	Domestic	63.58%	61.67%	61.67%
10%	International	73.66%	68.51%	68.51%	Domestic	69.74%	69.10%	69.10%
15%	International	71.55%	65.62%	65.62%	Domestic	68.41%	70.52%	70.52%
20%	International	76.57%	82.89%	82.89%	Domestic	73.04%	72.14%	72.14%
25%	International	76.35%	81.58%	81.58%	Domestic	82.34%	82.69%	82.69%
30%	International	75.75%	73.82%	73.82%	Domestic	76.58%	86.36%	86.36%
35%	International	83.68%	81.07%	81.07%	Domestic	75.00%	84.41%	84.41%
40%	International	80.78%	79.37%	79.37%	Domestic	74.97%	83.53%	83.53%
45%	International	76.90%	76.94%	76.94%	Domestic	79.48%	82.05%	82.05%
50%	International	76.99%	77.55%	77.55%	Domestic	80.35%	78.46%	78.46%
55%	International	76.29%	80.57%	80.57%	Domestic	78.15%	77.60%	77.60%
60%	International	72.44%	74.56%	74.56%	Domestic	80.35%	79.20%	79.20%
65%	International	75.84%	77.77%	77.77%	Domestic	80.85%	79.19%	79.19%
70%	International	85.03%	84.10%	84.10%	Domestic	83.19%	83.95%	83.95%

75%	International	85.51%	84.60%	84.60%	Domestic	81.28%	81.84%	81.84%
80%	International	88.98%	85.44%	85.44%	Domestic	87.37%	83.48%	83.48%
85%	International	90.01%	91.64%	91.64%	Domestic	85.73%	85.53%	85.53%
90%	International	94.42%	92.60%	92.60%	Domestic	91.91%	88.72%	88.72%
95%	International	97.24%	95.04%	95.04%	Domestic	95.87%	93.11%	93.11%
100%	International	99.13%	98.57%	98.57%	Domestic	99.12%	97.70%	97.70%

In conclusion, the analysis of accuracy in project management, considering 1, SPI and SCI performance factors, revealed consistent trends when comparing projects led by international and domestic project managers. Tables 3, 4, and 5 consistently demonstrate that projects supervised by international project managers consistently exhibit higher accuracy levels than those managed by domestic counterparts throughout the entire project timeline. This underscores a notable pattern suggesting that international project managers tend to achieve higher accuracy in project execution, emphasizing the significance of managerial expertise in achieving project objectives.

5.8 Guidelines Derived from the Above.

Following an in-depth analysis and meticulous calculations for project types, the subsequent phase involves extending our scrutiny to encompass the collective results derived from thirty distinct projects. This comprehensive examination aims to unveil overarching patterns and insights, shedding light on the most effective method for projecting project completion dates. Through a nuanced exploration of various facets and project durations, we endeavour to distil valuable conclusions that will serve as practical guidance for optimizing the accuracy of project forecasting methods.

- First and foremost, the Earned Duration method emerged as the most accurate among the three techniques across various metrics, including average accuracy, performance factor set to 1, and performance factor set to SPI Earned Schedule were the highest. However, under the performance factor set to SCI, both Planned Duration and Earned Schedule surpassed Earned Duration, achieving an accuracy of 81.52%%. This underscores the Earned Duration method's exceptional efficacy in predicting project completion dates across a diverse spectrum of project types and durations.

In Figure 30, the variation in average accuracy achieved by each method is illustrated. The gauge chart displays four categories, ranging from 0 to 25%, 25% to 50%, 50% to 75%, and finally, 75% to 100%, with each category represented by a distinct color as shown below.

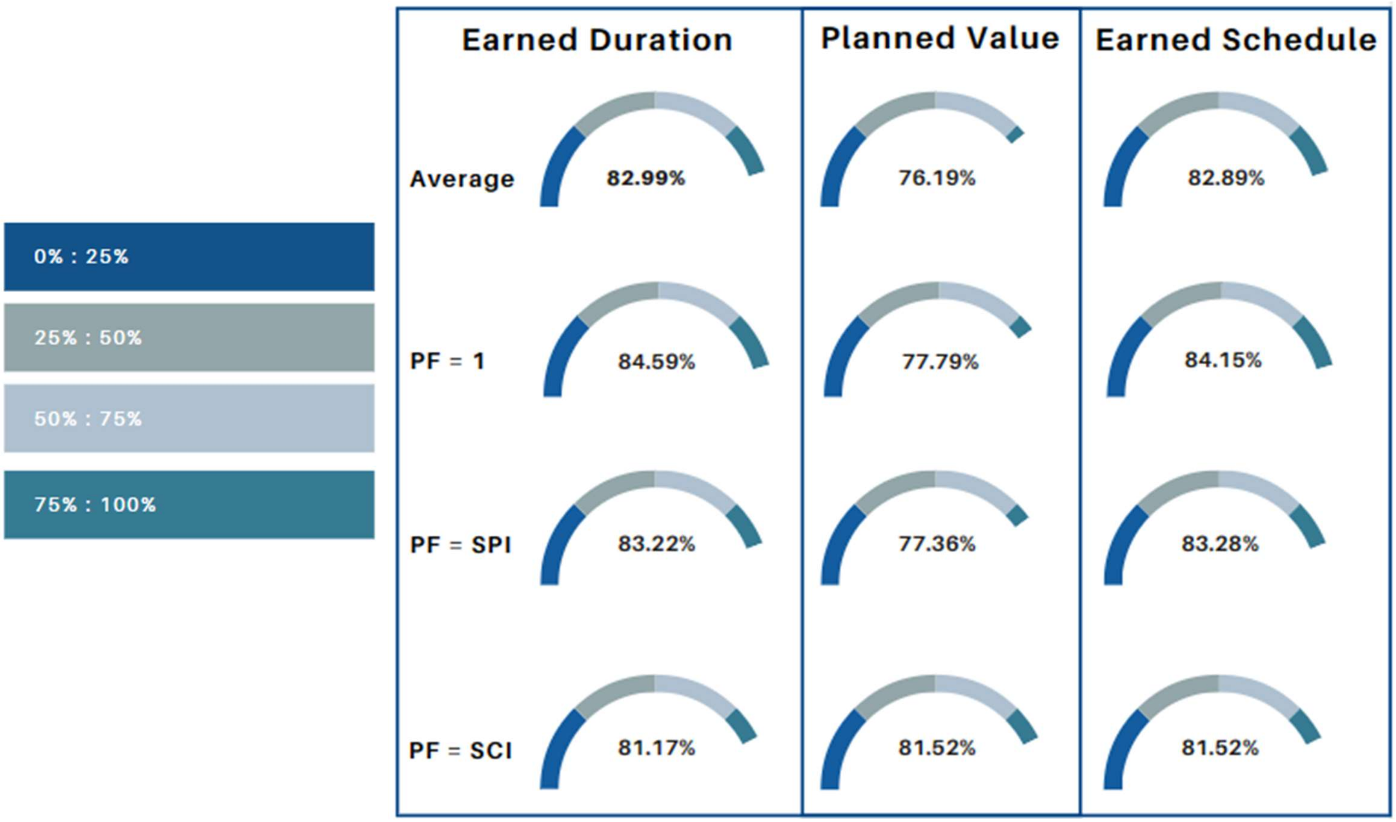

Figure 30 Overall accuracy achieved per method.

- Furthermore, the thesis unveiled a useful guideline for selecting the most efficient technique based on project duration percentages. These guidelines will assist project managers and practitioners in making informed decisions about which technique to employ for the most accurate project forecasting in general:
    1- For projects with a duration ranging from 0% to 20% of the total project timeline, the Earned Duration method is recommended.
    2- In the case of projects spanning from 20% to 50% of the project duration, the Earned Schedule method is the optimal choice.
    3- Projects in the 55% to 65% duration range are best suited for the Earned Duration method.

4- Between 65% and 70% of the project timeline, the Earned Schedule method proves to be the most efficient.

5- For projects from 70% to 75% of their duration, the Earned Duration method is once again the recommended technique.

6- In the 75% to 80% project duration range, the Earned Schedule method is the most effective.

7- Finally, for projects nearing completion, from 80% to 100% of the project duration, the Earned Duration method is the superior choice.

Figure 31 illustrates the best method to use over the project duration percentage as mentioned above.

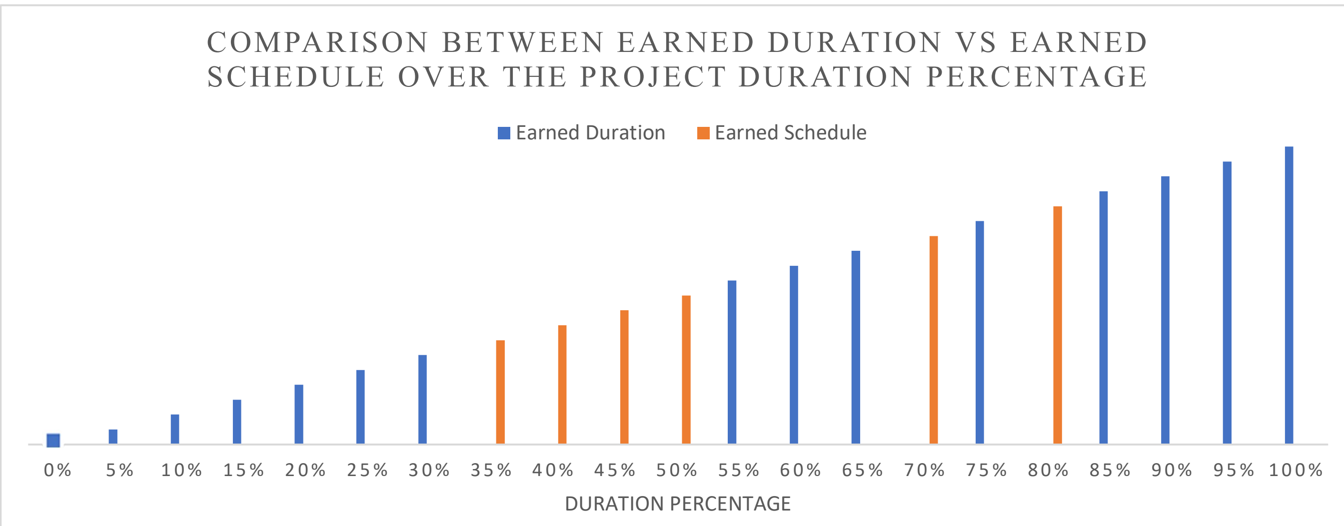

Figure 31 Comparison Between Earned Duration vs Earned Schedule over the project duration Percentage.

Additionally, the thesis introduced a practical guideline for selecting the most effective technique based on project duration percentages. These recommendations are designed to aid project managers and practitioners in making well-informed decisions regarding the choice of techniques for precise project forecasting when using a performance factor equal to 1:

1- For projects constituting 0% to 5% of the total project timeline, it is advisable to use the Earned Duration method.

2- Projects with a duration falling within the 5% to 30% range of the total project timeline are best suited for the Earned Schedule method.

3- Optimal results are achieved with the Earned Duration method for projects spanning from 30% to 60% of the project duration.

4- Projects with a duration ranging from 65% to 70% are most appropriately managed using the Earned Schedule method.

5- Between 70% and 100% of the project timeline, the Earned Duration method demonstrates the highest efficiency.

Figure 32 depicts the overall outcome when the performance factor is set to 1.

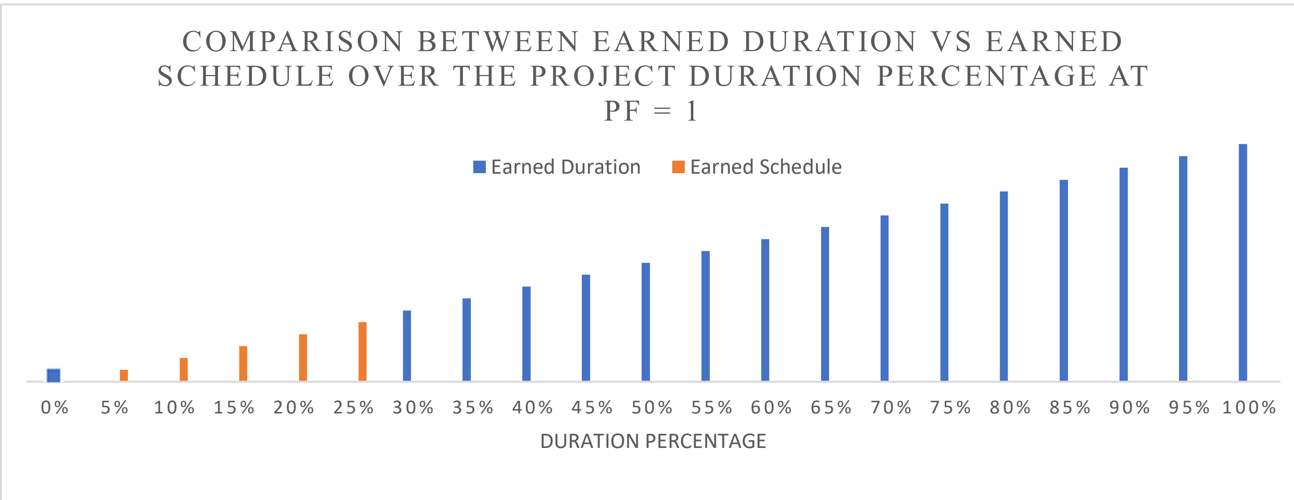

Figure 32 Comparison Between Earned Duration vs Earned Schedule over the project duration Percentage.

Moreover, the thesis introduced a valuable guideline for selecting the most effective technique based on project duration percentages. These recommendations aim to assist project managers and practitioners in making well-informed decisions regarding the choice of techniques for accurate project forecasting, particularly when employing the performance factor SPI:

1. It is advisable to use the Earned Duration method for projects constituting 0% to 30% of the total project timeline.
2. Projects with a duration falling within the 30% to 65% range of the total project timeline are most suitable for the Earned Schedule method.
3. Optimal results are attained with the Earned Duration method for projects spanning from 65% to 70% of the project duration.
4. Projects with a duration ranging from 70% to 75% are best managed using the Earned Schedule method.
5. Between 75% and 100% of the project timeline, the Earned Duration method demonstrates the highest efficiency.

Figure 33 illustrates the overall outcome when the performance factor is configured to SPI.

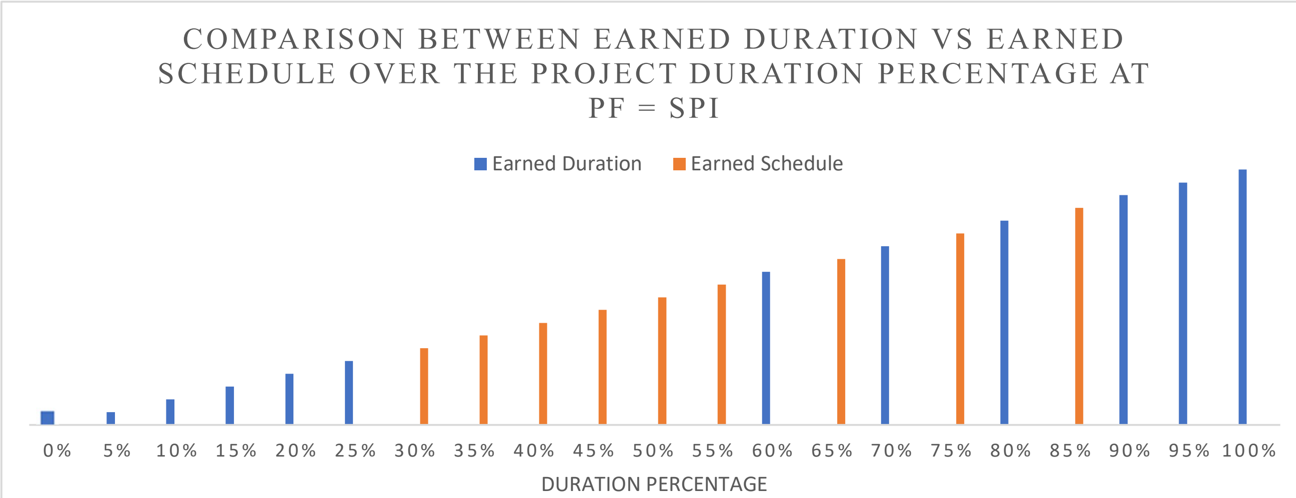

Figure 33 Comparison Between Earned Duration vs Earned Schedule over the project duration Percentage AT PF = SPI.

The selection of techniques for precise project forecasting when utilizing the performance factor SPI multiplied by CPI:

1. It is recommended to employ the Earned Duration method for projects encompassing 0% to 15% of the total project timeline.
2. Projects with a duration ranging from 15% to 55% of the total project timeline are most appropriately managed using the Earned Schedule method.
3. Optimal outcomes are achieved with the Earned Duration method for projects spanning from 55% to 60% of the project duration.
4. Projects with a duration falling within the 60% to 65% range are most effectively handled through the Earned Schedule method.
5. Between 65% and 70% of the project timeline, the Earned Duration method demonstrates the highest efficiency.
6. Within the 70% to 75% duration range, the Earned Schedule method exhibits the highest efficiency.
7. For projects constituting 75% to 100% of the project timeline, the Earned Duration method demonstrates the highest efficiency.

Figure 34 depicts the overall outcome when the performance factor is set to SCI.

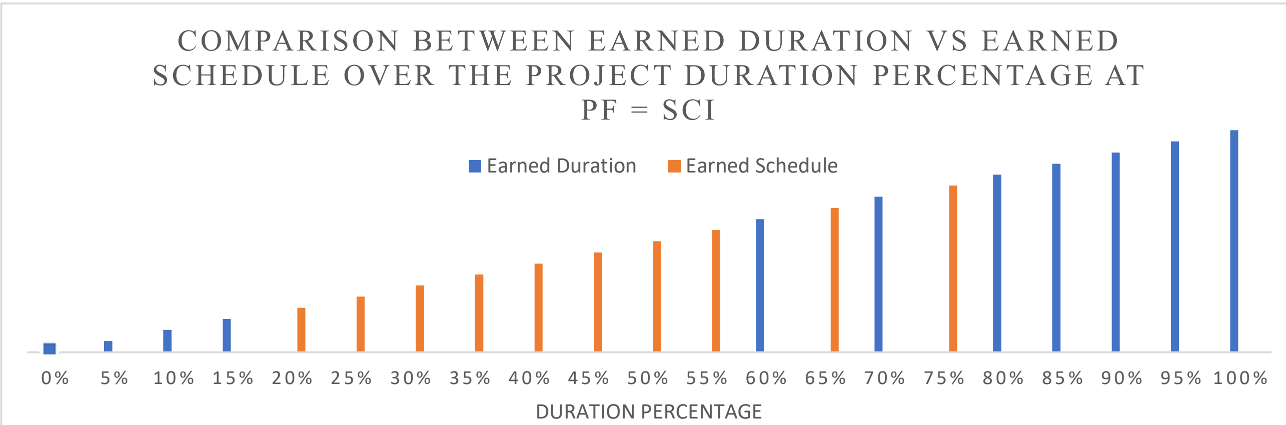

Figure 34 Comparison Between Earned Duration vs Earned Schedule over the project duration Percentage AT PF = SCI.

- The analysis considered each technique based on three essential performance factors: Performance Factor (PF) equal to 1, PF equal to Schedule Performance Index (SPI), and PF equal to SPI multiplied by Cost Performance Index (CPI). The Average comparison between the three methods is shown in figure 35.

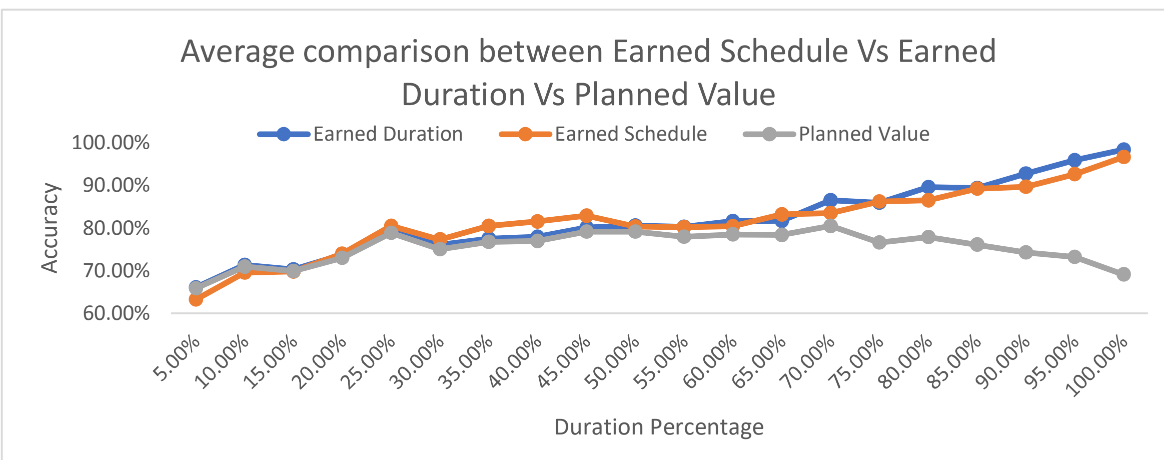

Figure 35 Average comparison between Earned Schedule Vs Earned Duration Vs Planned Value

The findings from the projects indicate the following:

1- When evaluating the performance factor (PF) as 1, or simply assessing whether projects were completed on schedule without considering cost and schedule performance, the Earned Duration method consistently emerged as the superior technique with 98.88% very close to earned schedule percentage which is 98.71% as shown in figure 36.

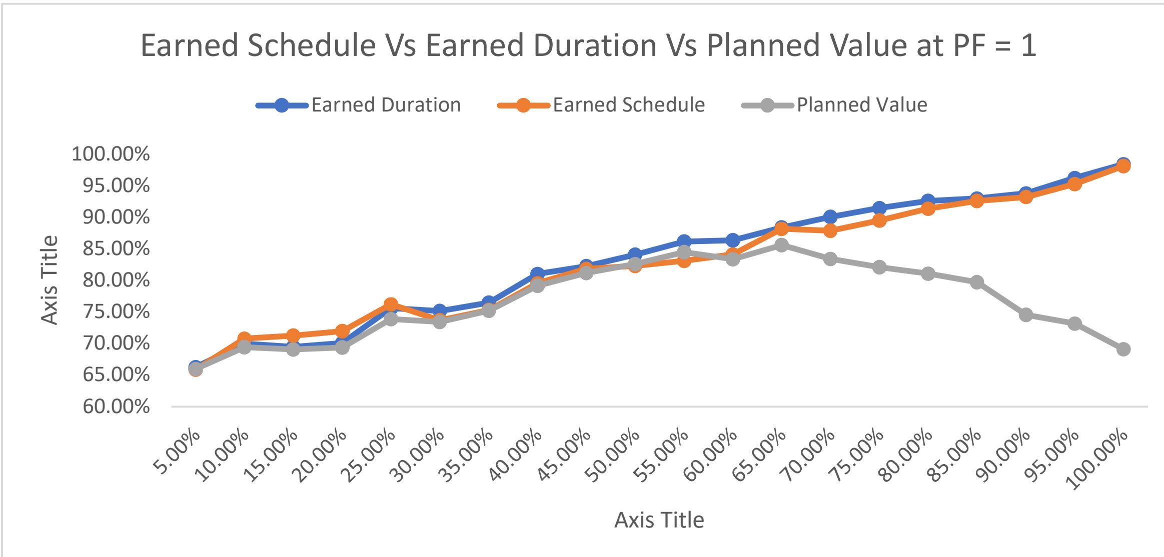

Figure 36 Earned Schedule Vs Earned Duration Vs Planned Value at PF = 1

2- Similarly, when focusing solely on the Schedule Performance Index (SPI), which measures schedule adherence regardless of cost performance, the Earned Duration method consistently displayed the highest accuracy as shown in figure 37.

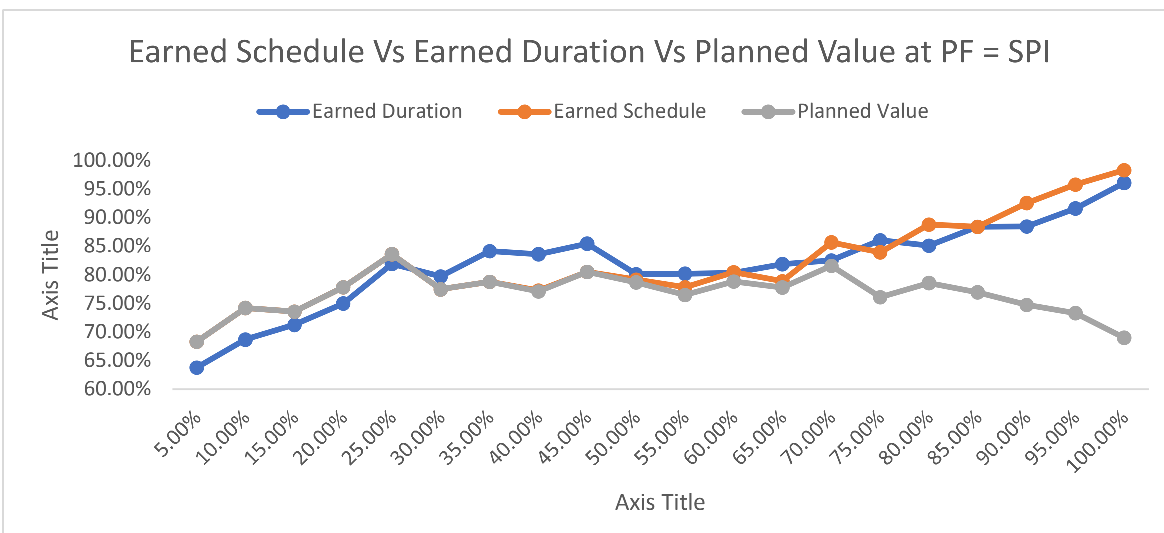

Figure 37 Earned Schedule Vs Earned Duration Vs Planned Value at PF = SPI

3- Notably, when considering both schedule and cost performance together, represented as PF = SPI x CPI, both the Earned Duration and Earned Schedule methods achieved the same level of accuracy. This indicates that in scenarios where both schedule and cost performance are vital considerations, these two methods provide equally reliable results as shown in figure 38.

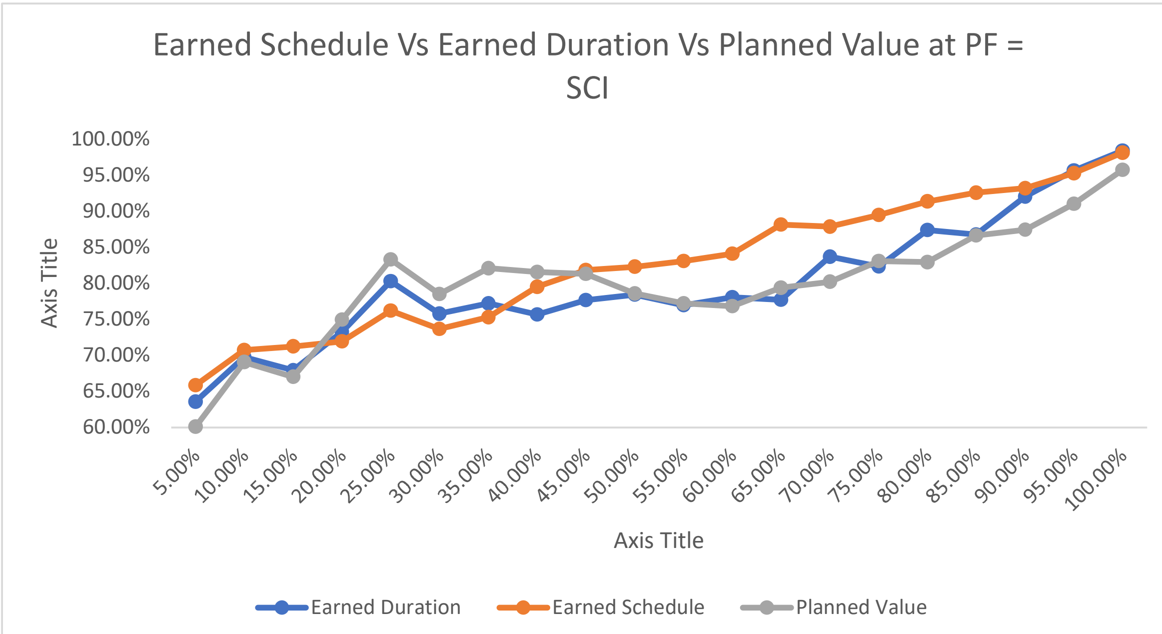

Figure 38 Earned Schedule Vs Earned Duration Vs Planned Value at PF = SCI

In a similar fashion, encompassing the project types, the subsequent outcomes were derived from the examination of both industrial and commercial projects in table 4.

In industrial projects, the highest accuracy throughout the project duration is consistently attained with the earned duration method, particularly when employing the performance factors equal to SPI and one. In some instances, the earned schedule also emerges as a leading method. Similarly, for commercial projects, the pattern is largely analogous to industrial projects, with earned duration predominating in most phases of the project timeline. In the context of educational projects, earned duration consistently secures the highest accuracy across a significant portion of the project duration percentages, while earned schedule and planned value take precedence in certain duration percentages. The overall outcomes are shown in table 4 which illustrates the methods and performance factors with highest accuracy according to duration % and project industrial, commercial, and educational.

Duration %	Type	PF	Method	Accuracy	Type	PF	Method	Accuracy	Type	PF	Method	Accuracy
5%	Industrial	1	ED	61.91%	Commercial	SPI	ED	69.76%	Educational	SPI	ED	79.76%
10%	Industrial	SPI	ES	72.08%	Commercial	SPI	ED	69.47%	Educational	SPI	ED	84.76%
15%	Industrial	SPI	ED	72.61%	Commercial	SPI	ES	72.77%	Educational	1	ES	83.11%
20%	Industrial	SPI	ES	80.72%	Commercial	SPI	ED	76.12%	Educational	SPI	ED	86.00%
25%	Industrial	SPI	ES	78.88%	Commercial	SPI	ED	82.09%	Educational	SPI	ED	89.50%
30%	Industrial	1	ES	73.94%	Commercial	SPI	ES	76.57%	Educational	SPI	ED	92.70%
35%	Industrial	SCI	ED	83.90%	Commercial	SPI	ES	84.46%	Educational	SCI	ED	95.53%
40%	Industrial	1	ED	77.18%	Commercial	SPI	ES	81.29%	Educational	1	ED	89.95%
45%	Industrial	1	ED	79.57%	Commercial	SPI	ES	88.65%	Educational	1	ES	91.52%
50%	Industrial	1	ED	79.23%	Commercial	1	ED	82.67%	Educational	1	ES	92.10%
55%	Industrial	SPI	ES	82.36%	Commercial	1	ED	85.18%	Educational	1	ES	95.02%
60%	Industrial	1	ED	80.55%	Commercial	1	ED	86.10%	Educational	1	PV	94.74%
65%	Industrial	SPI	ED	86.97%	Commercial	1	ED	88.94%	Educational	1	PV	94.10%
70%	Industrial	SPI	ED	88.86%	Commercial	1	ED	90.93%	Educational	1	PV	94.75%
75%	Industrial	SPI	ED	89.96%	Commercial	1	ED	91.56%	Educational	1	ED	95.32%
80%	Industrial	SPI	ED	90.66%	Commercial	1	ED	92.76%	Educational	1	ES	97.54%
85%	Industrial	SCI	ES	93.80%	Commercial	1	ED	93.50%	Educational	SCI	ED	96.34%
90%	Industrial	SPI	ED	93.98%	Commercial	1	ED	93.10%	Educational	SCI	ES	98.20%
95%	Industrial	SPI	ED	96.61%	Commercial	1	ED	96.05%	Educational	SCI	ES	97.67%
100%	Industrial	SCI	ES	99.18%	Commercial	SCI	ED	98.58%	Educational	SCI	ED	98.98%

Table 5 Industrial, commercial, and educational projects comparison based on duration percentage.

Similarly, considering the various project types, the subsequent results were obtained through an analysis of both educational and renovation projects in table above. Finally, incorporating the project types, the following results were obtained through the examination of renovation projects. However, it should be noted that this may not be a robust measure, as only one project was utilized in this analysis in table 6.

Table *6* method and performance factors with highest accuracy according to duration % and project type (Educational and Residential)

Duration %	Type	PF	Method	Accuracy	Accuracy	Type	PF	Method	Accuracy
5%	Residential	SPI	ED	77.52%	10%	Renovation	1	ES	93.43%
10%	Residential	SCI	ES	85.39%	15%	Renovation	1	ES	93.45%
15%	Residential	SPI	ED	79.52%	20%	Renovation	1	ES	93.46%
20%	Residential	SPI	ED	84.59%	25%	Renovation	1	ES	99.86%
25%	Residential	SPI	ED	94.52%	30%	Renovation	1	ES	93.46%
30%	Residential	SPI	ES	89.02%	40%	Renovation	1	ES	97.84%
35%	Residential	SPI	ED	93.73%	45%	Renovation	1	ES	97.79%
40%	Residential	SPI	ES	97.27%	50%	Renovation	1	ES	99.94%
45%	Residential	SPI	ES	95.36%	55%	Renovation	SCI	ED	99.10%
50%	Residential	SPI	ES	95.55%	60%	Renovation	SCI	ED	99.85%
55%	Residential	1	ED	92.48%	65%	Renovation	1	ES	99.94%
60%	Residential	1	ES	91.68%	75%	Renovation	1	ES	99.87%
65%	Residential	1	ES	92.76%	80%	Renovation	1	ES	99.97%
70%	Residential	1	ES	93.53%	85%	Renovation	1	ES	97.84%

75%	Residential	1	ES	94.49%	90%	Renovation	SCI	ES	99.26%
80%	Residential	1	ES	95.45%	95%	Renovation	SCI	ED	98.13%
85%	Residential	1	ES	91.32%	100%	Renovation	1	ES	100.00%
90%	Residential	1	ED	94.95%					
95%	Residential	1	ED	95.05%					
100%	Residential	1	ED	96.68%					

Table 6 Residential and renovation comparison based on duration percentage.

Ultimately, by integrating the various project types, the subsequent results were derived through the comprehensive analysis of all projects, excluding consideration of specific project types. In general, the earned duration method proves to be the most effective throughout nearly the entire project duration. Concerning performance factors, it is generally advisable to utilize the schedule performance index (SPI) for up to approximately 50% of the project duration. Subsequently, employing the performance factor equal to 1 emerges as the preferred approach to attain optimal results.

Duration %	PF	Method	Accuracy
5%	SPI	ED	68.36%
10%	SPI	ED	74.25%
15%	SPI	ED	73.59%
20%	SPI	ED	77.84%
25%	SPI	ED	83.64%
30%	SPI	PV	79.74%
35%	SPI	PV	84.19%
40%	SPI	PV	83.66%
45%	SPI	PV	85.48%
50%	1	ED	84.08%
55%	1	ED	86.16%
60%	1	ED	86.35%
65%	1	ED	88.42%
70%	1	ED	90.05%
75%	1	ED	91.47%
80%	1	ED	92.60%
85%	1	ED	92.96%
90%	1	ED	93.79%
95%	1	ED	96.22%
100%	1	ED	98.42%

Table 7 Overall Projects highest accuracy achieved based on duration percentage.

In conclusion to the discussion chapter, future research directions could involve implementing the identified findings and assessing their accuracy. A valuable avenue for exploration would be to compare the outcomes of this study with subsequent measurements, analyzing any differences in accuracy between the initial and subsequent results. Additionally, while the study delved into various EVM techniques and highlighted their limitations, future research might explore alternative approaches for comparison.

Moreover, the study raises questions about the continued reliance on EVM, emphasizing the need for proper improvements to potentially enhance the application of these techniques in upcoming construction projects. It is worth noting that the research did not address the construction of a model for future estimations, leaving room for further investigation in this area.

The next chapter, Conclusion, will serve as the culmination of this research journey, summarizing the essential discoveries, outlining practical implications, and suggesting avenues for further exploration. Our exploration of EVM within the construction landscape will come full circle, providing a comprehensive understanding that bridges theory and practice.

the implementation of EVM within the Egyptian construction industry presents notable challenges pertaining to application, accuracy, and result interpretability. Despite these challenges, there exists a significant opportunity to leverage technological advancements and develop a refined, controlled EVM approach that can markedly enhance project management practices.

This research aims to contribute to this enhancement by conducting a thorough evaluation of Earned Duration, Earned Schedule, and Planned Value methods in the context of a diverse array of 30 construction projects across various sectors in Egypt. Spanning commercial, educational, industrial, renovation, and residential domains, these projects were analyzed for their accuracy in forecasting completion dates, with a focus on identifying the most efficient method based on project duration percentages.

The comprehensive study covered a significant timeframe, from January 15, 2015, to December 30, 2023, providing a robust foundation for the findings. Notably, the Earned Duration method emerged as the most accurate technique across multiple metrics, including average accuracy, performance factors set to 1 and SPI. However, under the performance factor set to SCI, both Planned Duration and Earned Schedule surpassed Earned Duration, emphasizing the need for nuanced considerations in method selection.

While Earned Duration consistently proved effective for industrial, commercial, and educational projects, the Earned Schedule method outperformed in renovation and residential contexts. The thesis not only shed light on the most accurate methods but also provided practical guidelines for selecting techniques based on project duration percentages, offering valuable insights for project managers in the Egyptian construction sector. The introduced guidelines, tailored to different performance factors, serve as a roadmap for informed decision-making, contributing to improved project forecasting accuracy and overall project management practices. The applicability of these recommendations underscores the importance of aligning the choice of technique with the unique characteristics of each construction project, thus enhancing the reliability and efficiency of the forecasting process.

Furthermore, the investigation prompts inquiries regarding the ongoing dependence on EVM, underscoring the necessity for substantial enhancements to potentially elevate the efficacy of these techniques in forthcoming construction projects. Importantly, it is essential to highlight that the study did not encompass projects beyond the geographical scope of Egypt.

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