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A Review and Mapping of Project Schedule Monitoring Methods

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Abstract

Schedule control is fundamental to project success, enabling proactive management of deviations from the baseline plan. While Earned Value Management (EVM) provides solid results for analyzing schedule performance, its limitations prompted the exploration of alternative methods. This study describes the drawbacks of EVM in schedule control. It then reviews and maps previous studies on schedule control and schedule risk analysis to describe, using a decision flowchart, how their findings relate to each other, and which method best fits the project characteristics and control priorities. The literature review was conducted using the PRISMA 2020 framework. The findings suggest adopting a top-down approach for serial networks and a bottom-up approach for parallel networks. Additional factors, such as the need for sensitivity analysis, uncertainty assessment, monitoring, or forecasting, further refine the selection of the optimal method. All above considerations were mapped in the decision flowchart provided which can be used by practitioners to identify the methods that best fit their case. This study provides insights into schedule control and clarifies the relationships between different methods, enabling empirical evidence-based decisions.

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1. Introduction

Meeting timelines is crucial to project success. Delays can increase indirect costs, like rentals and utilities, or trigger penalties. Ensuring timely achievement of milestones facilitates scheduling optimization and resource coordination. This is especially valid when work is delegated to external contractors.

From the management perspective, schedule performance depends on the effectiveness of the control actions while executing the project. These actions are developed based on the expected time variance at completion, i.e., the difference between revised and planned durations. However, forecast accuracy depends on the methods used and the reliability of the baseline schedule.

Regardless of the reliability of the project baseline, risks can impact project execution and delay its completion. Therefore, effective schedule control depends on schedule risk analysis (SRA).

SRA can be conducted using bottom-up or top-down approaches [1]. Bottom-up approaches use distributions to simulate task duration, identifying the critical path to determine the project duration. Alternatively, top-down approaches analyze potential variations in schedule overall performance to forecast the project revised duration [2].

Literature on schedule control and SRA is extensive. While bottom-up methods vary in focus and approach adopted, top-down studies primarily rely on Earned Value Management (EVM) and its extensions. In EVM, schedule performance is assessed by comparing the budgeted cost of work performed against the performance measurement baseline, which comprises the budgeted cost of work scheduled values from the project's start to its planned duration.

EVM limitations have prompted research into bottom-up and top-down SRA approaches. A common challenge within these studies is understanding how their findings relate, and which method best fits the project under consideration. This study aims to improve schedule control by investigating the relationships between schedule-control methods, project characteristics, and tracking priorities.

The study is structured as follows. This section introduced the background of the study. The next section provides an overview of EVM, outlining its advantages and limitations. The Methodology section details the two-step literature review process. The Results section summarizes the included studies and analyses their interrelationships. Finally, the Conclusions section emphasizes the limitations of the study and suggests future research streams.

2. Earned Value Management

2.1. Overview

EVM emerged as an extension of the Cost Schedule Control System Criteria (C/SCSC) to address the limitations of the Critical Path Method (CPM) and of the Program Evaluation and Review Technique (PERT) [3]. Such tools neither provided performance measurement methods nor project duration forecasting techniques [4].

Schedule analysis in EVM relies on two metrics: Planned Value (PV) and Earned Value (EV). PV denotes the budget allocated to the work scheduled for completion for a specific date. Instead, EV denotes the budgeted cost of the work accomplished at a point in time [5].

Standard EVM quantifies project schedule performance using two indicators: Schedule Variance (SV) and Schedule Performance Index (SPI). SV denotes the difference between EV and PV (i.e., SV = EV - PV), which represents the monetary value of the deviation from the planned schedule. Instead, SPI denotes the ratio of EV to PV (i.e., SPI = EV/PV), measuring how efficiently work progresses. SPI also serves as a factor to estimate the Time Estimate at Completion (TEAC) using the formula TEAC = PD / SPI, where PD is the project Planned Duration.

EVM performance depends on the reliability of planning and budgeting processes. Both SV and SPI rely on EV and PV, which derive from the Work Breakdown Structure (WBS). The WBS integrates project scope, schedule, and budget [6]. Thus, for accurately evaluating schedule performance, the project budget must be allocated to work with corresponding schedule assignments in such a way that current progress can be compared against contract milestones.

2.2. Pros and Cons

EVM has many pros. First, it provides early warnings on the potential evolution of the project schedule, allowing managers to take control actions preventively [7]. Second, by applying activity-based costing to EV and PV, EVM facilitates progress communication across all management levels, enhancing project visibility and accountability [8].

Despite its pros, EVM has limitations. Major limitations include its reliance on budget metrics for schedule tracking, emphasis on current performance, use of fixed duration estimates, and disregard for project network complexities. These limitations often deter project managers from fully trusting in EVM.

Relying on budget metrics (i.e., EV and PV) has also its limitations. First, it assumes a linear relationship between the value of work and actual progress. This does not hold true down when task durations and budgets do not align (e.g., long tasks with low budgets) or when milestone budgets do not reflect the work required [9]. Furthermore, SV cannot directly calculate TEAC, and SPI converges to one as the project nears completion, masking any delay [10].

EVM forecasting techniques only consider current performance, ignoring both past trends and the nature of future work [11,12]. This assumption does not hold true when management actions or external risks (both opportunities and threats) may influence the project. Additionally, EVM calculations for TEAC lack context, as their reliability depends on whether project performance has stabilized, a factor EVM does not consider [13].

Concerning risk, EVM treats task durations as deterministic point estimates [14]. Consequently, the methodology does not offer a range of potential outcomes for project completion, nor does it calculate probabilities associated with the TEAC.

EVM has a significant limitation in its disregard for project network properties, offering no distinction between critical and non-critical activities [2]. Additionally, EVM neglects resource constraints, which could be potential bottlenecks. This is arguably the most stringent limitation, as it's the primary focus of bottom-up SRA studies. Last, it does not take into account risk considerations when forecasting [15,16].

2.3. Research Gap

EVM limitations have fueled multiple research streams, each tackling specific shortcomings. While these studies have made progress in schedule control, a comprehensive framework for understanding their relationships is lacking. Such insight is crucial for selecting the most appropriate methods based on the project characteristics and control priorities. Therefore, this study will review the existing literature and explore the connections between the proposed schedule-control methods.

3. Methodology

The literature review was conducted following the PRISMA 2020 framework. The framework comprises three sequential steps: identification, screening, and inclusion.

For the identification, all searches were performed on March 4th, 2024, using Scopus (https://scopus.com) and Google Scholar (https://scholar.google.com). The following search queries were used:

- "earned value management" AND "limitation",
- "project" AND "schedule performance index", and
- "project" AND "schedule risk analysis".

During the screening phase, several criteria guided the selection of relevant studies:

- Language: Documents written in English.
- Publication Type: Studies published in journals or conference proceedings.
- Citations: Studies cited at least once.
- Focus: Studies specifically addressing project schedule control, proposing methodologies or indicators, and offering practical insights.

Included studies were categorized by their approach (top-down, bottom-up, or hybrid) and the nature of their contributions. To clarify the relationships between these contributions, a decision flowchart was created.

4. Results

The results are described as follows. The search identified a total of 526 studies (226 from Scopus and 300 from Google Scholar). After deduplication (n=41) and removal of studies lacking citations (n=140) using automated tools, 345 studies remained. A further screening based on relevance to the research question yielded 194 studies for full-text retrieval. Following application of the eligibility criteria through citation searching and full-text review, 26 studies were included in the final analysis.

Table 1 outlines the approach (top-down, bottom-up, or hybrid) and the original contribution.

Table 1: Studies analyzed, approach, and contribution.

Study	Approach	Contribution
[17]	Bottom-up	Criticality Index (CI)
[18]	Bottom-up	Significance Index (SI), Cruciality Indexes (CRIs)
[19]	Bottom-up	Uncertainty Importance Measure (UIM)
[20]	Bottom-up	Mean Duration Sensitivity Measure (MDSM)
[21]	Bottom-up	Project duration sensitivity to task durations considerations
[22]	Top-down	Earned Schedule Methodology (ESM)
[23]	Top-down	Planned Value Method (PVM)
[24]	Top-down	Schedule Recovery Rate (SSR)
[25]		Serial-parallel indicator (SP)
[26]	Bottom-up	Schedule Sensitivity Index (SSI)
[27]	Top-down	Schedule Control Index (SCoI)
[28]	Bottom-up	Management-Oriented Index (MOI)
[29]		Sensitivity information
[30]	Top-down	Earned Duration Management (EDM2)
[31]	Bottom-up	Triad MCS
[32]	Top-down	Change Point analysis (CPA)
[33]	Top-down	Regularity Indicator (RI)
[34]	Top-down	Control charts
[35]	Bottom-up	ES min-max
[36]	Bottom-up	Critical-Slack-Sensitivity Index (CSS)
[37]	Bottom-up	Project duration mean and standard deviation method (μ_p, σ_p)
[38]	Top-down	Z-number approach (ZEVM)
[39]	Top-down	Grey theory
[40]	Bottom-up	Critical Duration Index (CDI)
[41]	Top-down	Fuzzy Project Performance Evaluation (FFPE) System
[42]	Top-down	PMB Limits Categoriser (PLC)

After identifying the studies, the proposed methods and results obtained were analyzed. Figure 1 outlines the mapping of the considerations drawn. A flowchart was used to better clarify how each study and method proposed relates to each other.

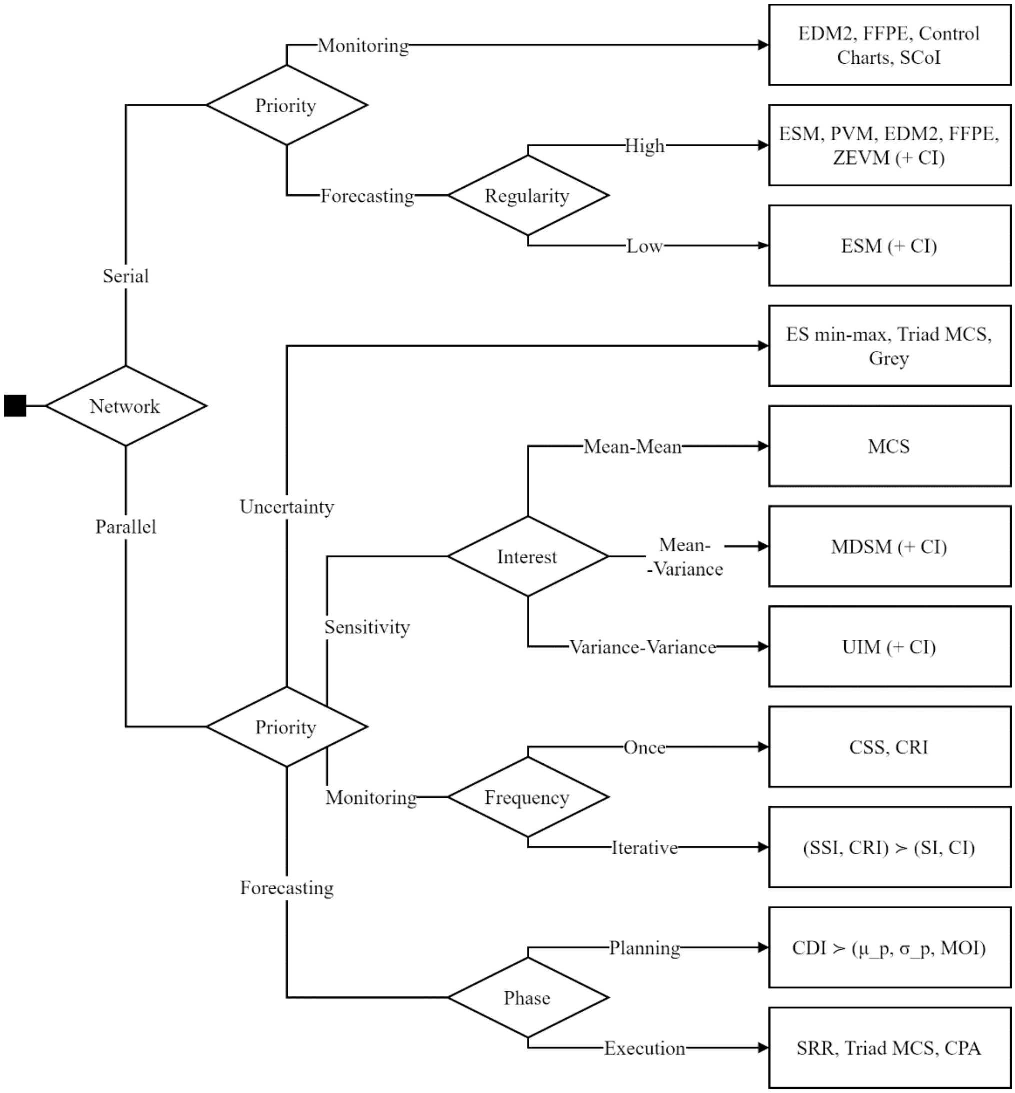

Figure 1: Control method decision flowchart.

The first decision node involves the project network seriality, which can be assessed using the SP indicator. [2]'s findings suggest using a top-down approach for serial projects and a bottom-up approach for parallel projects.

In top-down scenarios where monitoring is the priority, studies suggest EDM2, FFPE system, control charts, and SCoI are suitable. Instead, if forecasting takes precedence, project regularity becomes the key criterion. [42] recommends using the PLC indicator over RI to assess regularity. Then, according to [33], any method can be used for regular projects, whereas only ESM was proven accurate in irregular projects.

In bottom-up scenarios, four distinct priorities were identified: (i) assessing task duration uncertainty, (ii) evaluating sensitivity of project duration (mean or variance) to changes in task duration (mean or variance), (iii) monitoring for generating early warning, and (iv) forecasting the project TEAC.

For priority (i), ES min-max, Triad MCS, or grey theory are suitable methods.

Regarding priority (ii), [21] recommends the following methods based on the specific dependency of interest:

- Mean-Mean: Sensitivity of project duration mean to task duration means – use MCS.
- Mean-Variance: Sensitivity of project duration mean to task duration variances – use MDSM.

- Variance-Variance: Sensitivity of project duration variance to task duration variances – use UIM.

Additionally, any of these methods can be coupled with CI for further analysis.

About priority (iii), [36] using CSS followed by the CRI for una tantum monitoring, whereas they recommend followed by CRI rather than SI or CI for iterative monitoring.

For priority (iv), the method choice hinges on the estimation phase:

Concerning (iv), the choice depends on the phase during which estimates are evaluated: during planning, [40] recommends using CDI over μ_p, σ_p and MOI; throughout execution, SRR, triad MCS, or CPA are suitable.

5. Discussion

The literature review highlights a diverse landscape of methods that address EVM limitations in schedule control. This diversity reflects the complexity of projects, with factors like network structure, project regularity, and control priorities significantly influencing the suitability of specific methods. Top-down approaches show strength in early warning mechanisms. Instead, bottom-up approaches provide more granular control and flexibility in addressing task uncertainty. Importantly, the findings underscore that no one-size-fits-all solution exists, demanding a deliberate selection process based on project characteristics.

While the proposed framework offers guidance for schedule control method selection, several limitations must be acknowledged. First, the literature review, while informative, is not exhaustive, and further research could reveal additional methods or considerations. Additionally, since studies often utilize different datasets (real or simulated), direct comparisons of method performance may be challenging, introducing a level of uncertainty in the decision-making process. Finally, real-world projects often exhibit a hybrid nature, potentially requiring a combination of top-down and bottom-up methods for optimal control. For example, one can experiment using serial network-suggested monitoring and forecasting methods in parallel networks and vice-versa.

6. Conclusions

This study emphasizes the necessity of tailoring project schedule control methods to specific project characteristics and priorities. Recognizing the limitations of EVM, the proposed framework offers a valuable basis for practitioners to explore the range of available methodologies, facilitating informed decisions that enhance control strategies and increase the likelihood of project success.

Future research holds several promising avenues. First, extending the studies analyzed with professional and grey literature may reveal additional insights. Then, developing quantitative metrics for assessing project characteristics, such as network complexity or task interdependence, would reduce subjectivity and further refine the selection process. Integrating resource constraints and explicit risk analysis into the framework is essential, as these factors significantly impact project schedules.

Additionally, exploring the effectiveness of hybrid approaches in complex project environments is crucial. Such strategies could potentially leverage the strengths of both top-down and bottom-up methods to achieve optimal control. Further research on the optimal integration points between these approaches, and the development of decision-making tools to support the transition between them, is vital. By continuing to advance our understanding in these areas, we can empower practitioners to achieve exceptional project outcomes.

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